Improvement of Spain's regional railway system based off of Germany's railway model: Making R3 an efficient train line.

Gil Salvans Torras

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Thesis advisor: María del Carmen Moreno

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Abstract

This research aims to compare the Spanish and German regional railway mobility systems, by analyzing infrastructures which compose each network, services operating them and legal framework that comprises them. To make it the most accurate and realistic, two study cases are analyzed in depth: R3 of Rodalies Renfe and RB22 of DB Regio Mitte. All of this composes the input to create an Improvement Project which will put forward and eliminate the innefficiecies of the Rodalies Renfe services based on the DB Regio experience.

Key words: railway, regional, Deutsche Bahn, Renfe, system, transportation, Rodalies, R3, RB22.

Resumen

Esta investigación presenta una analogía entre los sistemas ferroviarios regionales de España y Alemania, donde se analizan las dos redes ferroviarias y sus infraestructuras correspondientes, los servicios que las operan y sus respectivos marcos legales presentes. Para darle más precisión y aplicabilidad práctica, se analizan profundamente dos casos de estudio: la línea R3 de Rodalies Renfe y la RB22 de DB Regio Mitte. Todo esto conforma la base para crear un proyecto de mejora que expondrá y eliminará las ineficiencias de los servicios de Rodalies basado en la experiencia alemana de DB Regio.

Palabras clave: ferrocarril, regional, Deutsche Bahn, Renfe, sistema, transporte, Rodalies, R3, RB22.

Table of contents

1. Introduction

1.1. Presentation of the topic and motivations

In a context where private transport domains, roads are overwhelmed and CO_2 emissions keep increasing there is and there has to be an urgent need to palliate this situation. The solution is easier than what people think: it is all about management of the transport and a rational use of it. Here, the rail transport has to be the focus. A mean of transport that does not have to deal with traffic and is environmentally friendly. There are countries that are already working on it, but others that still have a lot of work to do. Northern Europe and Southern Europe are the two sides of the coin.

Following this line, Germany, is one of the countries with more railway history worldwide and nowadays has one of the most efficient and complex mobility system in the world. However, the railway system in Spain is one of the most criticized and less efficient in Europe, excluding the express line (*AVE*). Those two countries are going to be the selected ones for this project.

In terms of scale, the commuter rail and regional services are the ones that affect the population in their daily lives more directly, e.g. students or people that travel to work to another city, tourists or simply local travelers for leisure. The commuter rail network connects all the cities, towns and important centers of a specific metropolitan area. The regional rail network also connects the cities and towns of a region although being the middle step between the inter-urban and the long distance mobility services. In Germany, those services are covered by *DB-Regio* and *S-Bahn* respectively, and are sometimes overlapped services. In Spain by *Renfe-Regional* and *Renfe-Cercanías*, but as there it is more clearly defined, the focus is going to be just in *Cercanías*. So, as the commuter rail and the regional rail routes are sometimes overlapped –especially in Germany when it is a region with a metropolitan area-, the project is going to be based in *DB-Regio*, *S-Bahn* and *Rodalies Catalunya*.

After this initial and brief presentation of the topic, there is the need to expose the main reasons or motivations that generated my interest in choosing this topic and not another one.

First and foremost, the commuter rail trains of *Rodalies Catalunya* have been a problem for everybody at least once in their lives: major delays, some accidents, mechanical problems or taking too long to get to the destination made the impression to the users that this train service is inefficient. In personal terms, the fact of living in Vic and commuting every day from this city to Barcelona with public transport has become a big reason to study this topic in depth.

Additionally, having studied for a semester in Salzburg and consequently having been a regular user of *Detusche Bahn*, I have been able to get to know from a first person perspective the German railway mobility service. A worldwide known model for its efficiency.

Therefore, after having the experiences from both sides and a growing interest in transportation systems, a field where geographers should play an important role, are the starting points of this project. A study that is going to be a challenge for the complexity of the topic. However, it will demonstrate a wide range of capabilities of geographical methods and approach.

1.2. Objectives and hypothesis

Continuing with the introductory section, the main objectives to be achieved during and at the end of the project are listed below:

- Get to know in depth the middle distance railway mobility models in Spain (Catalan region) and Germany, being able to elaborate an accurate analogy.
- Be capable, after studying both railway models, to create a project of improvement for the Spanish model –being this based on the German model-.
- Analyze the different areas of study in order to thoroughly know the territory and base the whole project in a geographical approach.

Therefore, these three objectives are going to be the main guidelines of the project. Nevertheless, this is also going to be followed by some specific objectives that will provide concretion in the research:

- Identify the reasons of inefficiency of the *Renfe Cercanias* services.
- Analyze the way that the mobility is conditioned by the geomorphology or topography of the regions: Is the relief an excuse for *Rodalies Catalunya* and an advantage for *DB-Regio/S-Bahn*?
- Identify, besides its excellent fame, the weaknesses of the German regional railways.

On top of all the objectives and before initiating the corpus of this investigation there is an initial hypothesis. The issue that will be supported –affirmed or denied- during and at the end of the project. In this case, the hypothesis is very clear: “There are multiple lacks of efficiency in the current railway mobility model of Renfe-Rodalies Catalunya”, which are going to be put forward and resolved with a project of improvement based on the German mobility model.

1.3. Methodology

During the elaboration of the project, there has been a specific structure and methods that will be exposed in this section as well as the tools which have made it possible.

First, the investigation structure follows a deductive method, which expands from the general to the particular topics. In this case, it goes from the Spanish and German railway systems to the specific study cases (R3 Vic Barcelona section and RB22 line) and it ends with the consequent Improvement Project. Therefore, a general contextualization phase brings the research to the specific study issue and ends with the potential solution of it.

The information sources used over the investigation have been diverse. In the status of the subject and the starting sections, the use of research motors like Science Direct or Google Scholar has been basic to access all the bibliography and information. To complement this and advance it, official information such as governmental or federal departments –from Spain, Germany or the EU-, the railway companies' websites (DB, Renfe & Adif) or other articles specified in the bibliography section, have been consulted. Having this entire base, the study cases have been analyzed through a fieldwork phase, which will be subsequently explained, along with Renfe, Adif and Deutsche Bahn public data. Finally, the specific phases of the Improvement Project – diagnosis, prognosis, application and monitoring- have been elaborated according to the previous sections and some specific plans or projects such as the ones about the double track implantation for R3 (e.g. Plan de Cercanías 2008-15) have been consulted as well.

An important part of this project has been the data collection throughout two fieldwork phases. Both of them have been crucial to get a better understanding of the train systems and the specific selected routes. The first one was done in Frankfurt, where Andreas Trottmann –Engineer in DB Netz- and Ramona Fellner –Head of service strategy in DB Fernverkehr- showed the route RB22 personally, provided multiple figures and relevant data for the whole project, and all of this during three intensive days -7th to 9th of March- in which the German regional train system was entirely understood. Therefore, this first phase was mainly done by formal, informal conversations and improvised interviews from the aspects which were unknown or unclear, since the aim of it was to get an integral view of this mobility system and the Frankfurt-Limburg route. The second fieldwork phase was done in Spain and was less complex. It consisted in taking the R3 from Vic to Barcelona and back for one week. Through observation methods in this period, informal talks with Renfe staff –e.g. locomotive drivers- and users, and the experience obtained during the years being a Vic citizen and studying in Barcelona, the knowledge from this system and route was clear.

In methodological terms, some different softwares and techniques were used. For the data management and visualization through charts and tables, Excel has been the main tool. The cartography and GIS methods have been carried out with QGIS and ArcGIS. Additionally, this spatial data analysis has been complemented with the programming language SQL (Structured Language Query) in order to simplify the operations and optimize the procedures. This geoinformation and these figures used as the base to do all the methods mentioned have been obtained through the following institutions: ICGC, ESRI, Departament de Territori i Sostenibilitat, Adif, and Deutsche Bahn and Renfe open data portals. Finally, sections of the Improvement Project such as Diagnosis and Prognosis are made according to the following methods: a SWOT matrix and Problem Trees for the diagnosis in order to identify clearly the positive and negative aspects of the study object (R3 Vic-Barcelona section) and to make a more understandable and harmonic visual for the reader, as well as the prognosis which follows a tabulated method for a better structure and specification of the measures.

1.4. Project timetable

	DECEMBER				JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE			
	Weeks				Weeks				Weeks				Weeks				Weeks				Weeks				Weeks			
TASKS	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1. Definition of the topic, structure, approach and contents																												
2. Establishment of goals/objectives																												
3. Research of information/bibliography: theoretical framework and status of the subject																												
4. Research and analysis of the railway networks and services; system and actors																												
6. Legal framework																												
7. Research: the two study cases (Vic - Barcelona / Frankfurt - Limburg)																												
8. Fieldwork in Germany																												
9. Fieldwork in Spain																												
10. Analysis of the study cases																												
10. Improvement Plan composition (diagnosis, prognosis & monitoring)																												
11. Final methodology, conclusions and bibliography																												
12. Final edits																												
Project submission																												
Project presentation																										X		X

Fig1. Project timetable (Source: own elaboration).

Legend:

- Yellow: 5h per week or less
- Orange: between 6h and 10h per week
- Red: more than 10h per week

2. Theoretical framework and status of the subject

The scientific investigation and research about the railway has been one of the biggest topics of study in comparison to all the mobility studies and investigations in this big field. Its old origins, the incidence that it has had in the societies or environments and obviously the transformation power for the economies that it had being a revolution for all of them.

Many authors have discussed a whole range of topics or issues such as historic aspects, pure engineering questions like the design and the infrastructures, environmental studies related to the sustainable mobility, analysis of the different types of railway as the high velocity, etc. The rail transport started over 2000 years ago in the civilizations of Greece, Egypt and Babylon–using this the animal kinetic energy-(Train History, 2019), but the actual invention of the steam locomotive and the rail track was at 1820s (Yi, 2018) supposing this one of the main inventions for the Industrial Revolution. In the European context, it produced an acceleration to the economic growth, achieving the coordination of production through the organization of commodity/input markets by the progressive implementation of efficient transport and distribution networks (O'Brien, 1983). The 19th century was the period of implosion of the modern railway, becoming the reference point for many of the scientific investigations.

It was in this period when the accessibility was highly improved and the distances between municipalities experienced a big reduction. This improvement of the accessibility and the rupture of the distance barrier affected the demography, by bringing a municipal population growth due to the crowding and urbanization effects (Koopmans et al, 2012). Another fact related to the railway improvement was the increasing of the flow of people between places that affected directly to the accommodation industry. David Bowie (2018) –researcher and lecturer in Oxford University-, studied this fact doing an evolution from the 1700 to 1900's with the focus on the English hotel industry.

During this century also, the implementation of the railway network was a generalized phenomenon within Europe. At that time, these networks were mostly operated by private railways and by many different companies; the national networks had many disparities –were not unified- until the railway nationalization triggered the fairly homogeneous network (Schram, 1997). According to Professor Jordi Martí-Henneberg (2013) from Universitat de Lleida, 70% of the lines that are currently in service had already been established by 1900; we are mostly still using a 19th century network. Therefore, a period of industrialization and increasing modernization, where the railway had a key role for this development; trends in agriculture, manufacturing and tourism, clearly correlate with the railway network development (Turnock, 2001).

Continuing with the chronological timeframe, the 20th century tended more to the development of the trains and locomotives and technological innovations as the dieselelectrical train or the high velocity. The scientific research based on this period is mostly based in certain areas or countries, and has a more specific approach. The technological development and the implementation of rail network was still ongoing; it was not a short process. It took the time span of the 19th and 20th centuries to be consolidated.

Asia was one of the more studied territories during this period. Asian railways were characterized by their heterogeneity: when countries like China needed to improve their passenger-operation efficiency, others like Vietnam or Malaysia needed to increase their cargo-operation efficiency (Wanke et al, 2018). The case of China –in the Asian context- has been the most studied during this period. The evolution of the spatial accessibility improved the economic growth significantly and configured the urban systems of China by using the “concentric rings” railway network with its core in Northern China (Wang et al, 2009).

The Nordic European countries –Denmark, Sweden, Norway and Finland- have been additional empirical proofs of the key role of the railway transportation in the industrialization of a country. Before this phenomenon, these countries were poor peripheral regions of Europe. Over the last century, they have become the richest part of the continent. The railway network connected all the areas of each country, making them able to trade and grow economically (Enflo et al, 2018).

Another important issue that emerged in the 20th century was the private or public property of the infrastructures and railway services. On one hand, by privatizing, the competition between companies and the target to maximize the profits were the solutions to reach efficiency and make a competitive service. On the other hand, having public infrastructures separated from the train operations, in which these operations are led by a private company concerted with the state, the aim is to guarantee a public service to the citizens (Gómez-Ibáñez & de Rus, 2006). This topic remains unanswered in the most recent investigations.

Until the second part of the 20th century, as seen in the articles, most of the investigations are related to the role of the railway in the development of the countries –in urban and economic terms especially- and the accessibility improvement. After this period, when the railway networks are already implemented in all the countries, the scientific investigation tends to focus on other issues such as the management, the environmental impacts, the analysis of the models, etc.

According to the researchers of the CAS Beijing –Institute of Geographic Sciences and Natural Resources- Fengjun Jin and Jiao Wang (2004), the railway evolution is characterized by four stages: initial stage, constructing stage, extending stage and optimizing stage. The first stages took part during the 19th and the 20th centuries, becoming a process of consolidation of the railway transportation. Preceding the first three stages, the optimization process, is still ongoing today with the target of efficiency.

In order to optimize the railway networks and services, there has to be good management; it is the solution to most of the inefficiencies. According to the simple and short definition of the Cambridge English Dictionary, management consists in the activities that control or organize something. Bringing this definition to the railway field, it controls and organizes the railway activity, status of the network, and the train service. However, this is very general and the last research explains it with different examples or approaches.

The train and track maintenance is one of the most important activities that make the train network and facilities work without technical problems. A planned and monthly scheduled maintenance guarantees a better quality in the service, more safety for the passengers and reduces potential costs. This is possible with a daily monitoring of the track conditions and the use of enhanced genetic algorithm methods specifically developed and adapted to the railway maintenance problem (Zhang et al, 2012).

The traffic management is another important aspect to consider in the railway operator companies. The flow of freight and passenger trains keeps increasing, making the railway companies improve the train's timeliness. This is also one of the problems that the train users are directly affected: punctuality. However, there is also a proposal to improve the traffic management. This proposal consists of centralization of the control of the traffic on real time using computational algorithms and modelling the actual data (Dotoli et al, 2013).

Having those last two cases as examples, the IT revolution has brought multiple solutions to all scientific and social fields. Using computational methods based on data that has been there for years, it is possible to create management models for every aspect of the railway mobility in order to bring this transportation closer to efficiency. Currently, many authors approach their investigations with the use of IT in the railway management. In addition, in a competitive context of today´s sectors of transportation, railways play a new important role within them. This is thanks to the potential awareness of environmental impacts and the search for increased safety of mobility (Profillidis, 2014).

To sum up with the chronological timeframe that has gone from the modern railway implantation to the present situation by analyzing some of the relevant investigations of this period, it is time to go on detail; the focus of the project. The territorial impact of the railway is clear and total, that is the reason why most of the scientific research are based on specific regions or countries. Having said that, it is time to focus on the areas of study of the project: Spain and Germany.

2.1. Status of the subject in Spain

The railway transportation has been main topic in lots of scientific studies by Spanish authors or researchers. Its impact in urban development, criticizes about inefficiency or solutions to promote and improve this means of transport. As it is noticeable in most investigations, the railway in Spain has helped a lot in industrial, urban and economic development, but has always been criticized and had lacks of functioning.

In the middle of the XIX century, the first Spanish railway was constructed. In terms of infrastructure, Spain was late in relation to other European countries. Due to the lack of private initiative and inhibition of foreign capital, the Spanish government decided to construct –using public funds- the first and big line; connecting Irún with Cádiz, going through Madrid, with two deviations to the Mediterranean – one to Málaga and the other to Alicante- (Pascual, 1999). Since this date, the railway transportation has gone through stages of creation, development and maturity. However, in the last century there has been a depression period. Proof of that is that in 1950 Spain transported the 51% of its goods. In 1990, just a 5% of these goods. A huge public expense, emergence of new and less expensive means of transport, lack of compromise of the Spanish state, unclear management between public and private sector or a fail of the Spanish concessional system are some of the main reasons that explain the decline of the railway in this country (Comín et al., 1998).

Other studies are focused on the urban changes which the railway network implementation produced. Bellet and Gutiérrez (2011) –researchers of Universitat de Lleida- studied the impact of the high-speed railway network in the urban structures of different Spanish cities. This phenomenon has brought many urban environments to their redevelopment. Horacio Capel (2007) –emeritus professor of Universitat de Barcelona and invested *Honoris Causa* doctor by many universities all over the world- , focuses his research on the configuration of the railway network in Spain and its impact in urban development. Professor Capel analyses the creation of the railway networks, fees, competition effects of automobile and privatization processes boosted by the European Union policies.

Investigations related to historic aspects of the Spanish railway have been also relevant to observe and analyze its evolution. Muñoz et al. (2005) studied the history of the narrow-gauge railway in terms of legal aspects and the companies that operate on this type by studying nationalization and liberalization processes that took part during the XX century. Another studied topic is reduction of transportation costs in Spain thanks to technological improvements, substitution of traditional transport means by the railway in the main routes of the country or the generalization of the automobile after the 1920’s (Herranz, 2005).

All in all, the Spanish railway trajectory –since the mid XIX century until today- has been a phenomenon of economic, business and territorial relationships with the state as a regulator and creator of the railway transportation policies (Cuéllar, 2007).

2.1.1. Status of the subject in Spain: In Catalonia

To get closer to the area of study of the project it is necessary to analyze the status of the subject in Catalonia. The region where Renfe Rodalies Catalunya operates which is focus of one of the study cases.

Industrialization in Catalonia took part during the second half of the XIX century. The Catalan region was starting to be industrialized, but as this process was unequal in the rest of the country, Catalonia was an industrial region fitted in an agricultural and poor Spain. During this period, the railway played a very important role and was one of the main agents of the creation of infrastructures. The position of the dominant classes and the industrial bourgeoisie was clearly determinant in the development of the rail network. Within this context, Pascual (1985) studied accurately this process during the XIX century. It is also Pascual (2000), the author who studied the profitability of the Catalan railways between 1849-1943 and calls them a big economic deception according to the big investment done and the type of interest in Spain during this period.

In Barcelona, the railway arrived in 1848. This caused important changes in the urban structure of the city and determined the subsequent development of Eixample. The emergence of different railway companies and following mergers, made the rail space and morphology to change and it had later consequences: non-coordination of those changes with the current project of Cerdà, incidence in the development of the communications system of the city or by generating severe urban inequalities such as slums (Alcaide, 2005). Nevertheless, the railway has historically been a connection element of the territory. Its network has been like a backbone for Catalonia; connecting all the population cores and conditioning their development. Prat (1994), studied this phenomenon by analyzing it specifically in the Region of Barcelona. Following the idea of the railway as a territorial connector, Camprubi (1996) analyzed this topic in the area of the Central Catalonia. The strategic role of Manresa which connected this Catalan region with Barcelona and the current Metropolitan Area, and with other parts of the territory such as the city of Berga.

As it is shown, most of the research based in Catalonia is either historical about the evolution of the railway/network or about the impact of this means of transport in the territory in terms of regions or in terms of urban structure.

2.2. Status of the subject in Germany

Germany has been a country of reference in terms of rail transportation since the railway implementation. Proof of that, it is the fact that most of the investigations about Germany and the railway are used as references for other countries. In other words, as a model for other countries to follow.

The German modern railway history was born in 1835 in Nuremberg, where the first steam train departed to Fürth. This was the starting point that would bring the country to its industrial revolution. In 1880, Germany already exceeded 33.800 km of rail track. A century led by the steam locomotives. This carried jobseekers and workers to the industrial areas, consequently making the cities and the new settlements rapidly grow. Mertens (2006) presented this timeframe history of the German railway going through the XX century –with the dictatorship and privatization in the 1990s- and until the XX century. In the most recent historical thematic, Bowers (1996) analyzed the railway reform in Germany, where the railway was affected by the privatization and the reorganization measures for an integrated railway system. Bowers also mentions the influence of the EU policies and creation of a railway law in 1993, which materialized this reform.

In India, the Indian Railways (IR) have gone through a process with high needs of reform due to its poor organizational structure. Although the Indian government have been scared of the unbundling measures since the negative experiences of the British Railways. Other countries like Germany have experienced organizational reforms successfully and have to be the model for India and the other countries in the same situation (Gangwar & Raghuram, 2017). Lithuanian railways have also been looking for an organizational and management reform. The search of efficiency and a competitive transportation system in Lithuania will be inspired on the Deutsche Bahn management model (Nikitinas & Dailydka, 2016).

In terms of pricing and competition between two different types of transportation –such as the bus and the train-, the German case has been particularly studied as a representative model of the European countries. The study shows that there is a clear relationship in the prices of the tickets because of the competition of means of transport. For example, the railway prices are lower on routes with intermodal competition in comparison to the monopolistic routes (Gremm, 2018).

Despite the fact that the good performance of the railway system in Germany there are also aspects that need to be improved such as the knock-on delays. Weik et al. (2016), proposed some mathematical methods to create a solution.

Having said that, it is noticeable that the German authors tend to focus their research on historical thematic or aspects that need to be improved, and the other investigations are mainly focused in Germany as the reference country in railway terms.

3. Railway systems in Spain and Germany

3.1. Spain

3.1.1. Spanish Railway Network

a) Evolution

The Spanish railway network has its origins in 1848 with the Barcelona-Mataró line. In 1855 the first railway law –*"Ley General de Caminos de Hierro 1855"*- was approved and from there, the expansion of the rail network became generalized in the whole country until the 20th century –see evolution in Fig.2. - . It was in the start of this century when the rail track longitude that composed the network was around 11.000km and Madrid was already connected with most of the peninsular peripheral areas. There was a need to connect the capital of the country with all the provincial capitals. It is because of this need that the network connected the Spanish territory in radial terms, with Madrid at the core of this structure.

During this 20th century, the growth became more moderate due to the political context –Civil war, changes of government, dictatorship- but by 1960s, the length of rail network still reached 18.000km. This last number has been the highest in the Spanish railway history. After the 1960s, the rail track distance that composed the network started to decrease regressively. This phenomenon happened because of the poor profitability and simplification of some of the routes (Franco, 2010). After a few years of stabilization and slight decrease of rail track kilometers, the implementation of a high velocity train named *AVE (Alta Velocidad Española*) in the beginning of the 21st century reversed the trend.

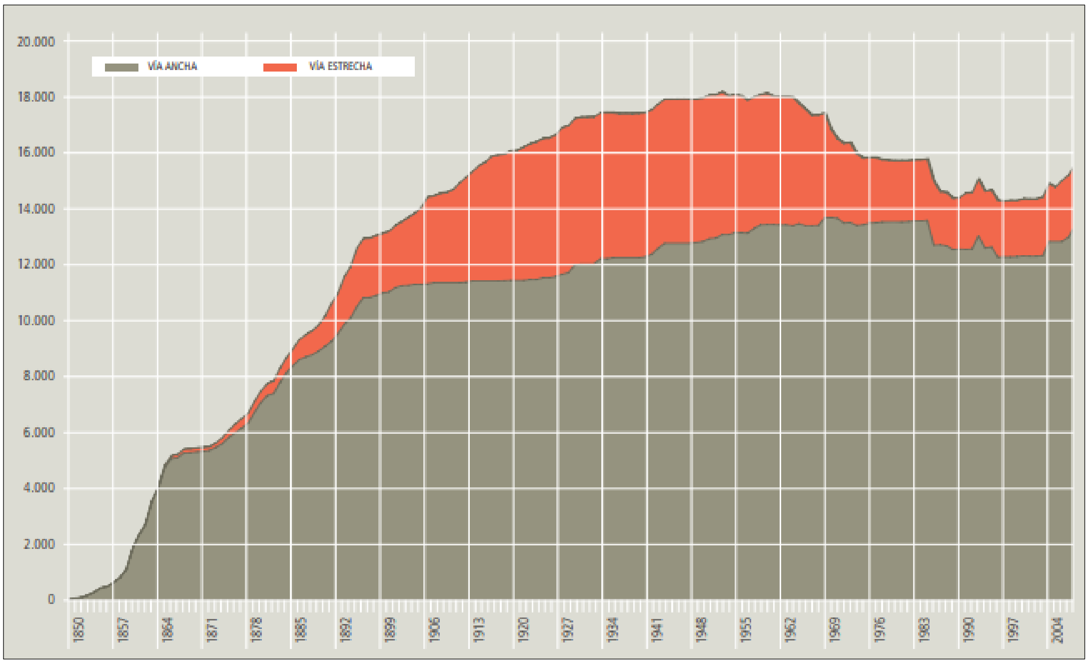


Fig.2. Evolution chart of the Spanish railway network from 1850 to 2007 in kilometers (Source: Carreras & Tafunell, 2008.)

Another important aspect to introduce is the track gauge. Currently in Spain there are three types of tracks depending on the gauge: Spanish/Iberian (1668mm), European (1435mm) and metrical/narrow (1000mm). Even though there are three, it is usually classified between wide or narrow –as the Fig2 chart represents-; >1668mm or <1668mm respectively. Therefore, the question is: why does Spain have wider track gauges than the rest of Europe?

Some authors hold a theory which says that if any country were to conquer Spain –especially France-, the conquerors would not be able to use the railway. Other authors put the reasons on the complex topography of the Spanish territory in which the wider track gauges are the better grip for the trains. Both of these theories are partially right. Nevertheless, the actual reason of these wider track gauges comes from a report of 1844 done by a technician commission. This report was responsible for this issue, in which it proposed wider tracks to make the trains able to drive faster. At the same time, as the tracks were wider, there was not loss of train stability.

As the chart Fig2 shows, most of the rail tracks in the Spanish railway network had and still have wide gauges because of the reason explained above. The rest of the network was and is still covered by narrow gauged rail tracks, which compose most of the local and secondary routes: some commuter services, goods transportation and a few regional lines (i.e. *Transcantábrico* line). To make it more understandable, the Fig.3 following maps –years 1855, 1905, 1941, 2011- illustrate the previously explained evolution of the network.

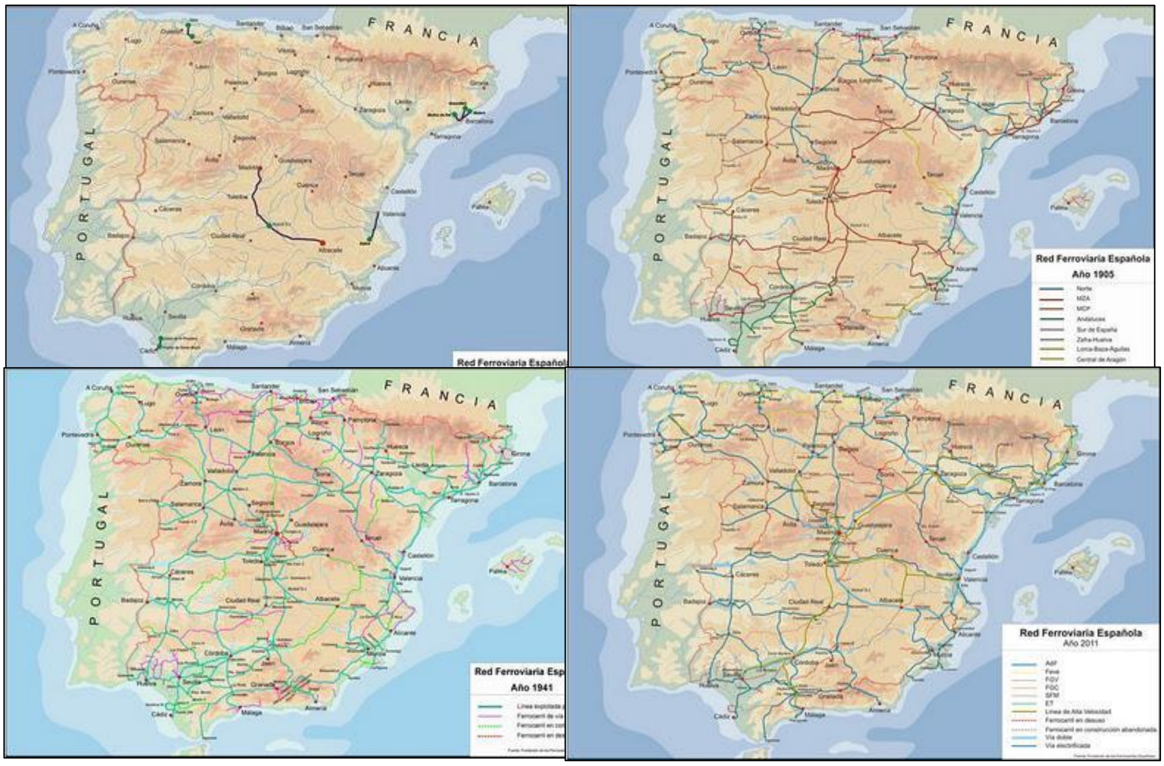


Fig.3. Evolution maps of the Spanish railway network. Period 1855-2011 (Source: Via Libre. La revista del ferrocarril, 2011).

b) The current network: RFIG

The Spanish Ministry of Development is the main organization in the railway sector of the country. This granted competences of infrastructure, construction and management to *ADIF (Administrador de Infrastructuras Ferroviarias*) and the service operation to *Renfe Operadora*. On one hand, *Adif* is a public company that belongs to the already mentioned Ministry of Development –maximum authority of the railway network-. On the other hand, *Renfe Operadora* is a state-owned business company that runs most of the railway transportation services in Spain and has the concession of the public railway services –which are theoretically liberalized-.

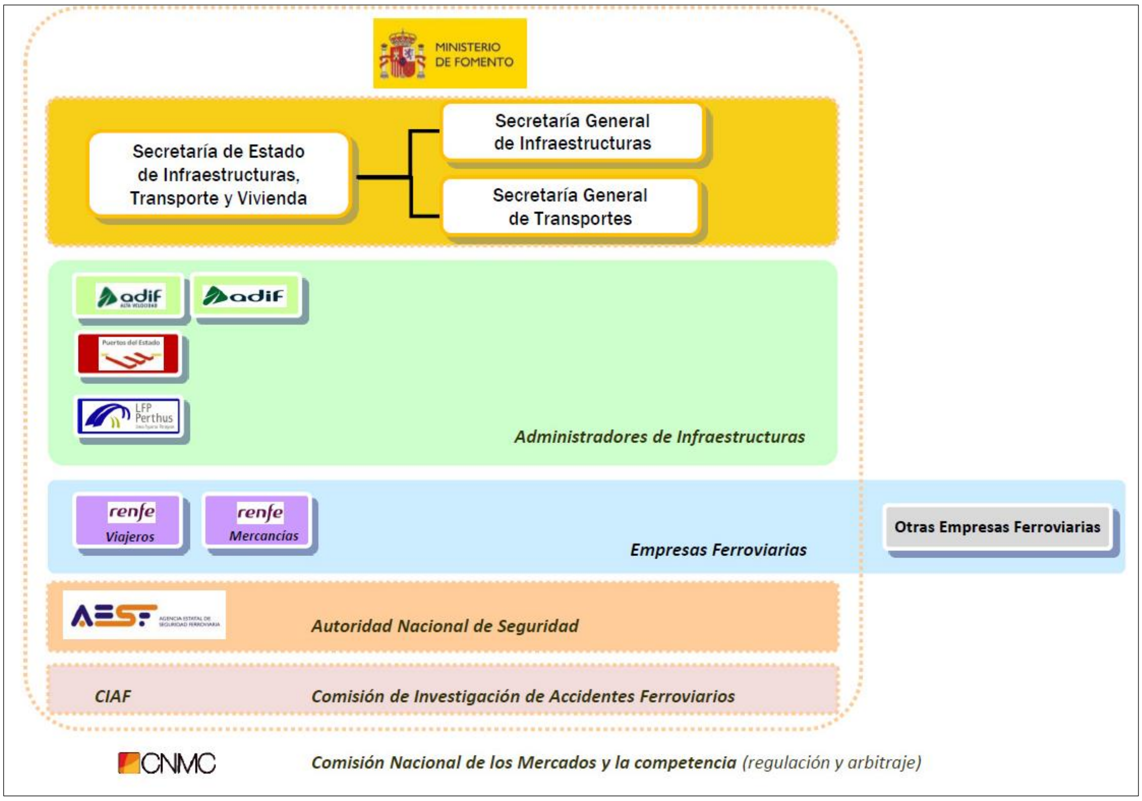


Fig.4. Structure and agents of the railway sector in Spain (Source: fomento.gob.es).

Having seen the important agents of the railway sector in Spain –Fig.4.-, it is time to analyze the current public railway network; the RFIG ("*Red Ferroviaria de Interés General*"). It is composed by the essential rail infrastructures with the target of guaranteeing a common railway service in the whole territory of Spain, in other words, to interconnect the country in terms of railway facilities. Since 2005, *Adif* is the managing company of this network –obviously under the rules of the Ministry of Development-. However, private property lines or the ones transferred to autonomous communities (CCAA) –such as *FGC* lines in Catalonia-, are not part of the RFIG. In this case, those other routes are not relevant for the study.

The longitude of RFIG corresponds to 15.301km of the rail track: 11.333km composed by Iberian gauge, 2.591km by European gauge, 190km by mixed gauge –Iberian and

European, and 1.207km by metrical gauge. It has 1.498 stations and the average national train flow is 2.206.905 trains per year (Ministerio de Fomento, 2018).

Fig.5. Map of the current Spanish railway network RFIG (Source: Adif).

According to the Fig5, the radial structure –with the core in Madrid- of the Spanish railway network is still present.

These past years, the implementation and development of the high-speed railway in Spain, *AVE*, changed the dynamics of the national network. The Spanish railway network has been declared the best in Europe in terms of quality due to this fact (IEE- Instituto de Estudios Económicos, 2016); more than 3000 km of high velocity tracks which brought Spain to the top of the world in railway terms. This caused a huge public investment that left the other railway types without budget; the whole public expense went towards *AVE*. The main consequence of this marginalization has been a polarization of the railway transport by having an excellent high-velocity quality versus a quite deficient commuter and regional rail quality.

In terms of utilization of the railway transportation in Spain, in 2015, out of 465 million users, just 30 million of them used the *AVE*. The other 435 million approximately were users of *Cercanías* and middle distance services (Fomento, 2015). Therefore, does that make sense? Absolutely not.

c) Catalan railway network

By reducing the scale and getting geographically closer to one of the study cases, it is time to see the Catalan railway network. In Catalonia there are two railway networks, the one that belongs to *Adif* –integrated into the RFIG- which is the actual Catalan railway network and one from *FGC –Ferrocarrils de la Generalitat de Catalunya-* which is a secondary autonomic network. Nevertheless, in order to simplify and make it easier they will be studied as a unique railway network –as it is shown in the following Fig6- integrated into the already explained RFIG.

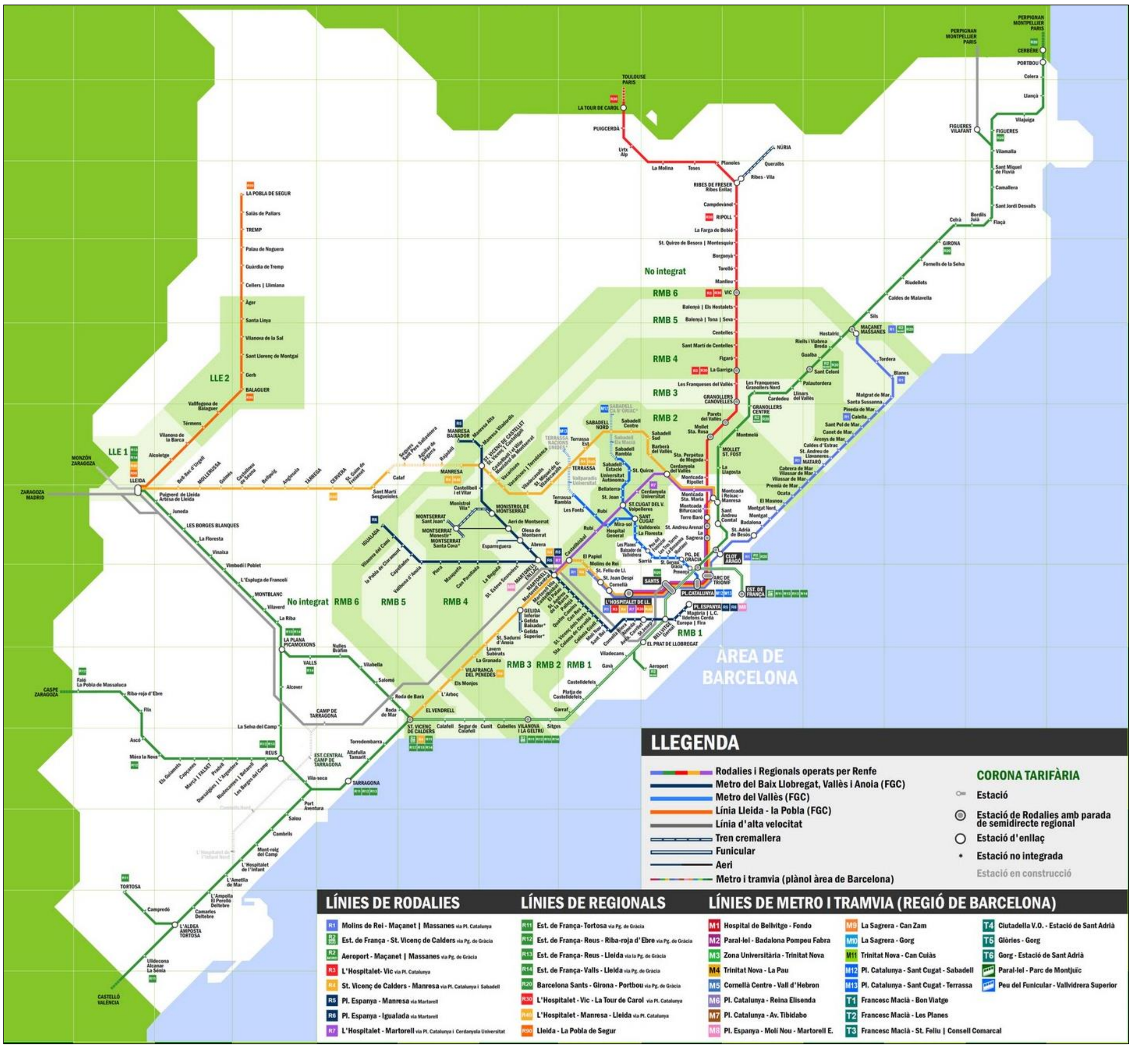


Fig.6. Map of the Catalan railway network (Source: senderismeentren.cat).

3.1.2. Railway services in Spain: Renfe Operadora

a) Overview

Renfe Operadora, as it is mentioned in the previous sections, is a state-owned railway company in charge of most of the railway service operations in Spain. The aforementioned RFIG, is entirely run by its services. This entity was founded in 2005, when the old RENFE (*Red Nacional de los Ferrocarriles Españoles*) was dissolved and split in two companies: *Renfe Operadora* and *Adif* with an operator from one side and the infrastructure manager for the other. Although, as the competences of service operations are liberalized, *Adif* is the entity that grants them, in which the current entity is *Renfe Operadora*-. This phenomenon happened in all the EU countries, due to the EU policies of unbundling and liberalization of the railway sector which modified the railway laws and organization of them; the EU obligates the concession of the non-commercial public services.

The organization of Renfe Operadora is divided in four axes: *Renfe Viajeros* (passenger train services), *Renfe Mercancías* (freight transportation services), *Renfe Fabricación y Mantenimiento* (rolling stock maintenance) and *Renfe Alquiler de Material Ferroviario* (rolling stock material leasing). These four sub-entities cover all the railway services and operations of the company. However, the interest will be focused on the passenger services.

Long distance, middle distance –including regional- , commuter rail (*Cercanías*) and narrow gauge rail services (*Renfe Feve*) are the different passenger services offered. The first type is mostly composed by high velocity trains –such as AVE, Alvia, Altaria and AVE-city- and partial high velocity locomotives –such as Talgo, Euromed, Trenhotel and Intercity-. The middle distance services are mainly composed by Regional and Regional Express lines –the first one stopping in more stations-, Avant –middle distance high velocity service- and by Intercity as well –routes between close cities-. The commuter rail lines are suburban railways that connect the inside and surroundings of a metropolitan area, and the narrow gauge rail services are the routes that composed the old FEVE network and are usually short lines of regional, commuter rail or even freight transportation. Each service mentioned above has its owns locomotive models.

In terms of fees, there is a difference between long and middle distance. In the first case, the price of the tickets varies depending on the route. In middle distance services, the general fee depends on the kilometers; the longer route the more expensive it gets.

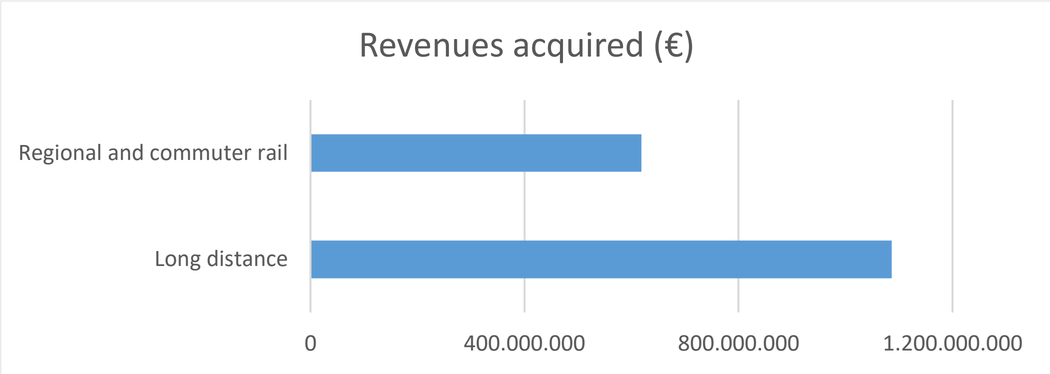


Fig.7. Chart of the revenues acquired in 2015 by middle and short distance and long distance services (Source: Own elaboration with Fomento 2015 data).

According to the Fig7 chart, the long distance services earn more money due to the high price of the tickets, because in terms of passengers as it is shown in the upcoming Fig8, the middle distance and specially the commuter rail services have much more demand.

Financing is another important aspect to take into account. The long distance services do not receive subsides from the state, unlike the middle distance and commuter rail services that do. Therefore, the long distance section is economically managed with its profits from the ticket sale.

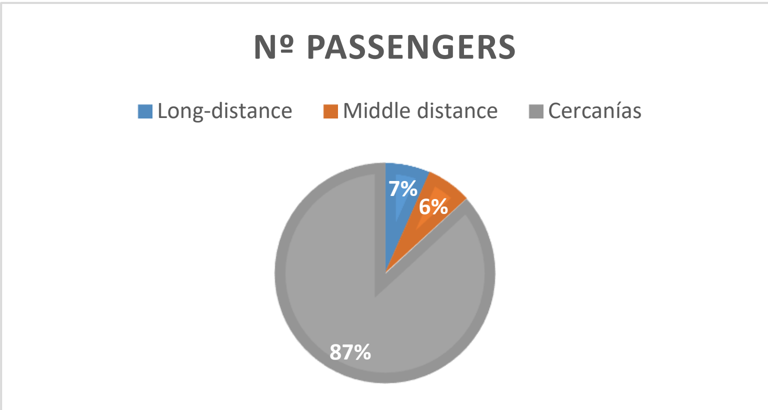


Fig.8. Circular diagram of the number of passengers split in the three services with its percentages (Source: own elaboration with Fomento, 2015 data).

b) Cercanías, Rodalies and Regional services

To get deeper into the section it is time to focus on commuter rail and regional services of Renfe, which are going to be the object of the later improvement project.

The regional services belong to the middle distance section of the company. Renfe Regional trains connect all the cities and towns with its province or autonomic capital. The commuter rail services have a very similar function, only with the difference of connecting the population cores within a metropolitan area in a suburban environment. These last services are called *Renfe Cercanías* and this name changes depending on the language of the region. In this case, the focus will be in the Catalan area where the name is *Rodalies de Catalunya*.

In practical terms, most of the middle distance services which connect the inside of a Spanish region are operated by *Cercanías*. However, when the routes are long and exceed the metropolitan territory, then the services are mixed with *Regional* –which operates in a radium of 300km-. One example is the route that will be the focus of this project –R3 from *Rodalies Renfe-*, where from *Barcelona* to *Vic* is entirely commuter rail and then from *Vic* to *La Tor de Querol* is mixed with the regional services.

For user services and fees the metropolitan area of Barcelona is managed by ATM (*Autoritat del Transport Metropolità*), so the commuter rail services of Rodalies Catalunya are also under this public company.

Fig.9. Map of the Spanish commuter rail (Cercanías) and regional network (Source: ferropedia).

The Fig9 map shows the connectivity of the Spanish territory through commuter rail services, where some of the routes that exceed its metropolitan area territory are operated by regional services. Therefore, the commuter and regional operations in Spain are highly coordinated, but is this an issue or an advantage?

This is going to be a question discussed in the upcoming sections of the project, but as of now, it looks like the governments are taking advantage of making the commuter rail routes longer and forgetting about the proper regional services. Proof of that is the Fig9, because as mentioned before, the Cercanías services are suburban and connect the territories within the metropolitan areas. So, according to the theory and looking at the map, people would think that Spain has multiple metropolitan areas when in the reality that is not true.

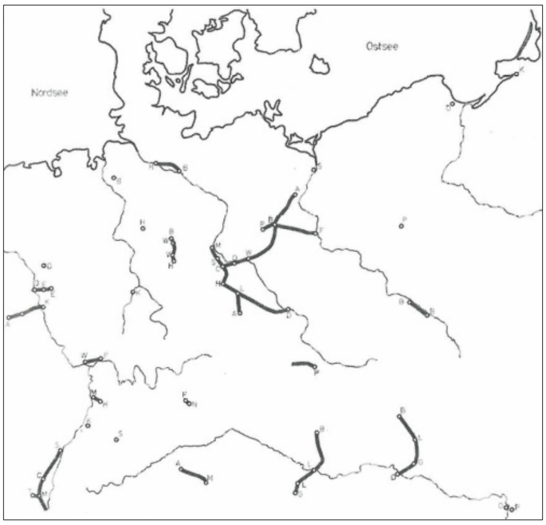
Finally, going back to the Catalan case, *Renfe* operates in this region without any legal base; the dealership finished in 2010. This situation happened because of the slowness of the liberalization process, in which the EU will fix this by 2024 and by then there has to be a public tender in *Rodalies* services.

3.2. Germany

3.2.1. German railway network

a) Evolution

The 1835 was the starting point of the German railway network with the route already mentioned Nuremberg-Fürth. From this year, the implantation of the network started to grow exponentially and by 1850, the German Confederation already had 5.875km of rail track. This was just the start of this growth, which in 1873 went up to 23.853km. Parallel to this length increase of the rail network, the users of the German railways were 783 in 1850, and raised up to 5.693 in 1873. In addition, the number of employees in the railway sector, capital stock or net domestic product of the German Confederation experimented an exponential growth (Wehler, 1995). This was just the start of a successful implementation.



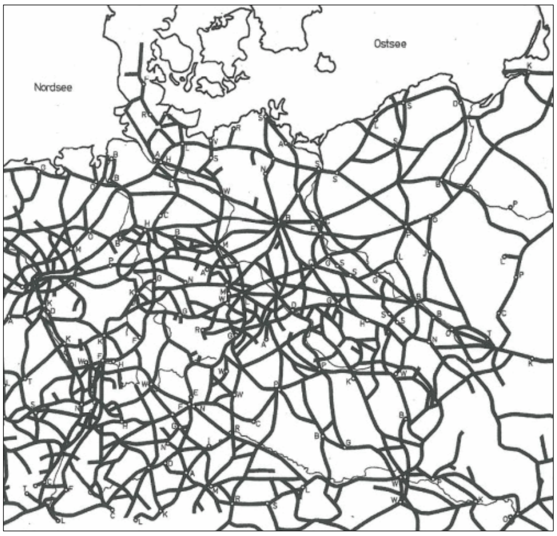


Fig.10&Fig.11. German railway network status in 1842 and in the late 1880s (Source: Weigelt, 2010).

Between 1880 and 1913, shorter routes were created in order to connect all the minor cities and the routes with more traffic were expanded with various lanes. This expansion and new creation of routes brought the German railway network to reach the 60.000km in the start of XX century (Monopolkommission, 2007). During the 1st World War, part of the network was used and controlled by the German army. After the war, the railway network and infrastructures were damaged and there was the urgent need to renew them. The same situation or even worse happened some years after with the 2nd World War, were stations and bridges were destroyed. The posterior division of Germany brought to the geographical division of the railway network: the east controlled by *Deutsche Reichsban* (DR) and the West by *Deutsche Bundesbahn* (DB). During the 1950s, some train routes were closed due to the poor demand and the huge generalization of private transport.

From 1990 and with the German reunification, the railway reform was carried out in 1994 with the merger of DR and DB that resulted in *DBAG*; the current company still in charge of the whole railway sector of the country, *Deutsche Bahn Aktiengesellshcaft*. Some of the train lines of Eastern Germany were renewed and modernized, and routes with insufficient traffic were closed. Because of this fact, there was not a big expansion as it is observable in Fig12, even though in qualitative terms the network changed entirely.

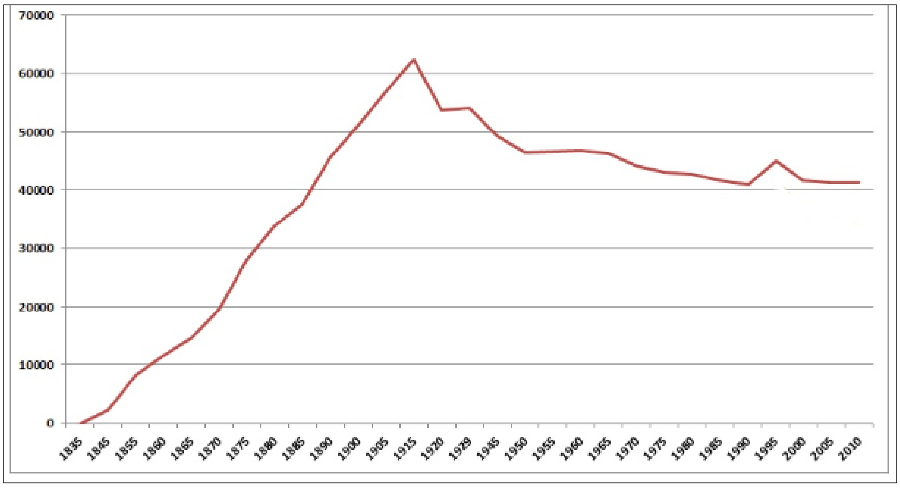


Fig.12. Evolution of the longitude of the German railway network in kilometers from 1835 to 2010 (Source: forschungsinformationssystem.de).

b) Current network

The German railway network is and has always been public. *DB Netz* is a company from the DB group that has the concession to create and manage all the infrastructures. So, the German Federal state contracts this company to build and maintain all the infrastructures which compose the entire network. To make it easier to understand, it is similar to Adif in Spain. According to this last analogy, *DB Netz* is in charge of the infrastructures and *DB Personenverkehr* is the main operator company within a liberalized railway system. Out of the 41.000 km approximately that compose the network, around 33.500 km are operated by the DB group companies mentioned above. During the railway reform of 1994, this company was put in charge of the majority of the sector as it is mentioned before, but always with the German government being the maximum shareholder. The rest of the routes of the network that are not operated by DB, are under the services of the non-federal railways (*NE-Bahnen*) but still in the *DB Netz* infrastructures. In other words, they are operated by the private railway companies that do not belong to the federal government.

The German railway system works in the following way: the federal government implements the rules and determines where the routes have to be and what their characteristics are –ex. A route from Frankfurt to Wiesbaden with double track conditions-. Following this, *DB Netz* creates the infrastructure and there is a public tender in order for the state to choose which company operates it. Under these conditions, just the operations are liberalized.

Depending on the use, there are two types of network; local and long distance. Intra-regional and suburban routes compose the local network, and the inter-regional or even international routes and usually most of the freight transportation routes compose the long distance network. Nevertheless, this very schematic division will be specified in the next sections depending on the service developed in each route.

In terms of gauge, the German rail tracks have mostly the Standard European gauge of 1.435 mm. In exception for example is the small private company *Harzer Schmalspurbahnen* (HSB) that operates 140 km of rail track in Harz –Northern Germany- with a narrow gauge network (1000 mm). Although, the federal railway network has the standard gauge.

In the EU context, Germany is the country with the longest railway network and the 6th in the world. However, this is just quantitative data that depends on the physical dimensions of the countries.

Relating to the investment of the railway infrastructure, Germany has a poor funding in comparison to other center and northern European countries (Fig.13.).

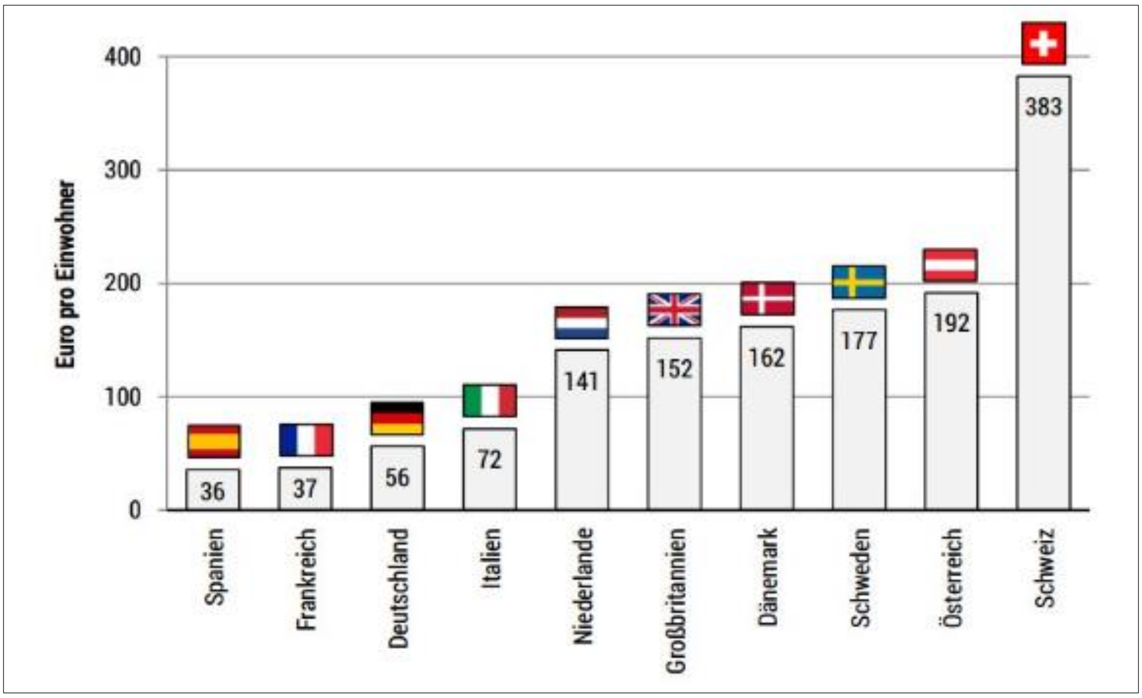


Fig.13. Investment per capita in rail infrastructure in 2015 (Source: Allianz Pro Schiene/SCI Verkehr).

During this last few years, the German federal government dedicated more part of its budget to roads and other infrastructures. This fact triggered with the fear of being less competitive than the Austrian or the Swiss neighbors. It also can carry future management consequences if it does not change at least up to 80 euros per inhabitant (Allianz Pro Schiene, 2015). In 2017, it increased up to 69 euros per inhabitant (Fig.14.).

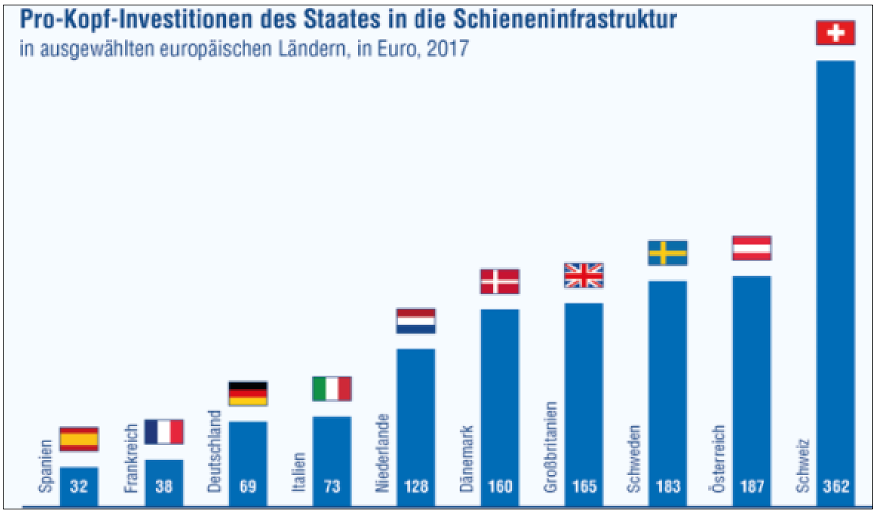


Fig.14. Investment per capita in rail infrastructure in 2017 (Source: Allianz Pro Schiene/SCI Verkehr).

Overall, Germany has a very long and complex railway network that has been developed within the last two centuries and adequate to the Central and Northern European context. A region where the railway transport has much more users and is seen as an urgent public need. Having said that and to sum up with the section, the following Fig.15. corresponds to the map of the German network.

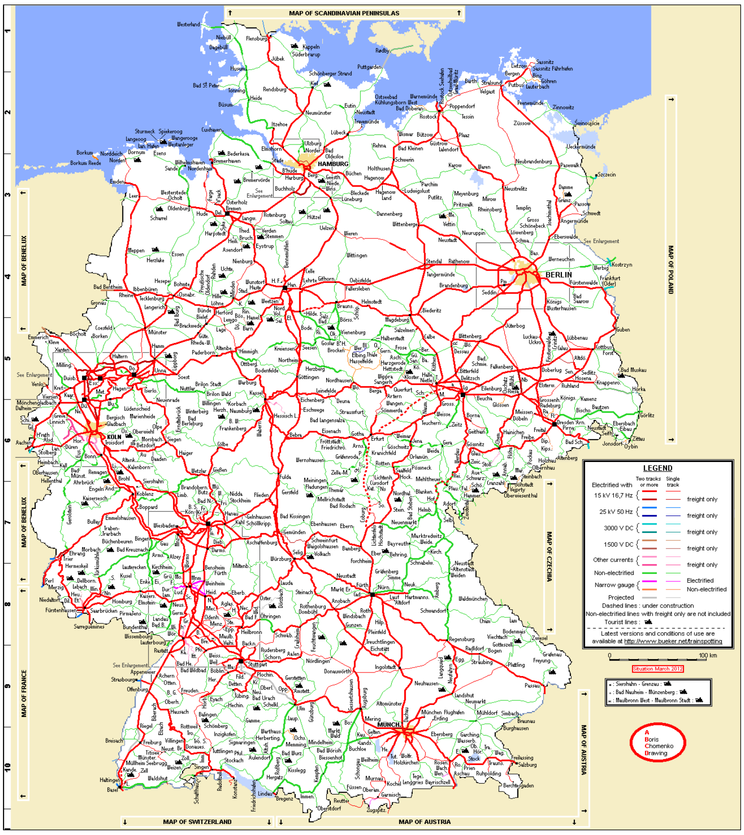


Fig.15. Map of the German railway network (Source: bueker.net, 2012)

3.2.2. Railway services in Germany: Deutsche Bahn (DB)

a) Overview

Deutsche Bahn AG is the German corporation that runs most of the railway services and is in charge of all the rail infrastructures of the country. It is a private corporation limited by shares –an *Aktiengesellschaft* in German-, in which the German federal government is the main and single shareholder. As mentioned before, DB operates 33.500km out of the 41.000km of the German railway network (81.7% of it). As this network is the largest in Europe and this corporation the main operator, the result is that DB is the largest railway infrastructure manager and operator in the continent.

A usual mistake is the relation of DB with the old *Deutsche Bundesbahn* due to the similarity of the initials. That is the reason why the current company is also officially abbreviated as DB AG *(Deutsche Bahn Aktiengesellschaft).*

In terms of organization, DB is subdivided in three autonomous companies in which 100% of the shares belong to DB AG. These three corporations are: *DB Personenverkehr*, *DB Netz AG* and *DB Schenker*. The first one is in charge of the passenger transportation –*Personenverkehr* "traffic of people" in English- and is divided in three branches; *DB Fernverkehr* for the long distance services, *DB Regio* for the short and medium distance services and *Arriva,* which is an external transportation company that *DB AG* owns and has all types of services around Europe. The second company mentioned –*DB Netz AG*- is in charge of the railway infrastructure management, and the third case –*DB Schenker*- is a logistic corporation that combines road and rail transportation. When it is exclusively road transportation the service is called *DB Schenker Logistics*, but when it is rail freight transport it belongs to *DB Cargo*. Like the previous section, the focus is going to be in the passenger transportation services.

According to Fig16, Deutsche Bahn approximately owns 15.000 regional locomotives and 253 high velocity trains (ICE: Inter City Express). In 2014, this entire float gave service to around 11.9 million of passengers per day.

Fig.16. Float numbers of Deutsche Bahn (Source: bahn.de).

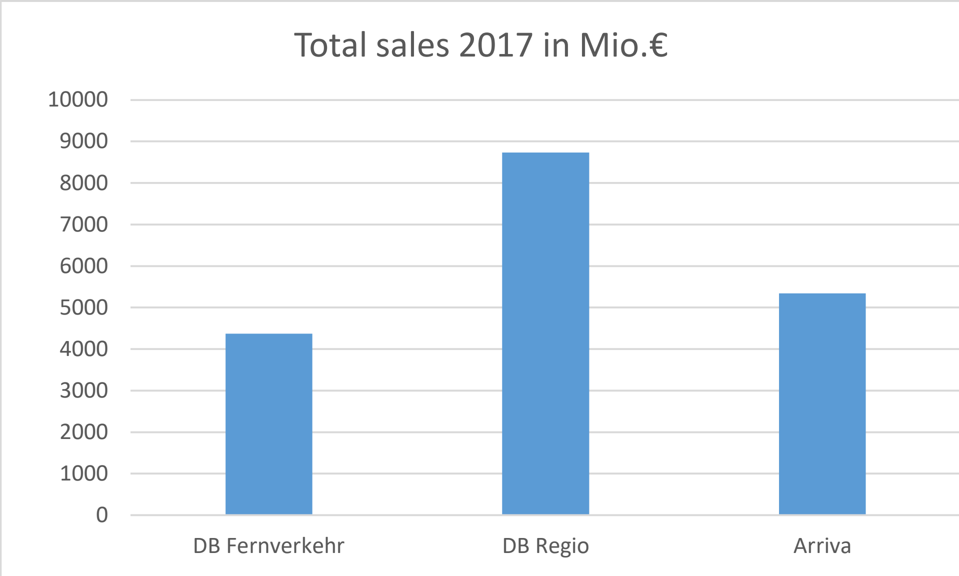


Fig.17. Chart of the revenues from the sales in 2017 in millions € (Source: Own elaboration with DB data).

In terms of income, most of the revenues of DB come from the middle and short distance operations of *DB Regio* as it is the most demanded service. In Spain it is also the most demanded sector, but the difference is that the *DB Fernverkehr* tickets are much cheaper than *AVE* tickets. In this aspect, Deutsche Bahn sales are well correlated with its number of travelers –see Fig17 and Fig18-. Another important aspect to mention is the funding of these two corporations inside DB Personenverkehr, in which DB Regio is subsided by the federal government and DB Fernverkehr is not.

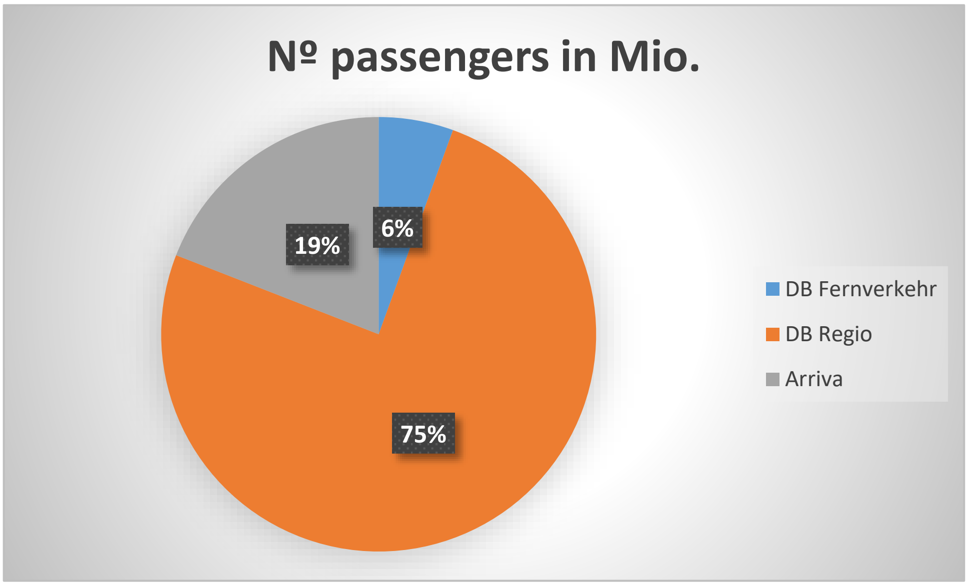


Fig.18. Circular chart with the number of passengers of each DB Personenverkehr service in million in 2017 (Source: own elaboration with DB data).

b) DB Regio services

The regional services of DB are under its respective *Bundesland* (federal state) authority. Unlike the long distance services that are entirely run by DB, the regional lines are planned and subsided by each regional government which are the ones who have the public transportation competences of each federal region. These governments have contracts with *DB Regio* that concede the company to operate those regional routes.

This corporation of DB is divided in two sections: *DB Regio Schiene* for the railway services and *DB Regio Bus* for the road services. Obviously, the focus is going to be in the regional railway service.

DB Regio Schiene operates the regional and the commuter rail lines of Germany. It divides the country in 7 functional regions depending on its extension and morphology e.g. *DB Regio Südost (SO)* –which occupies the states of Saxony, Saxony-Anhalt and Thuringia- or *DB Regio Bayern (BY)* –which occupies just the Bavarian state-. These seven areas –see them in the Fig.19 map- are just the general scope of work for DB. Each one has its own divisions and consequently various regional networks in order to connect the whole region. The zones that have a metropolitan area, like Berlin or Hamburg, are covered by commuter rail services called *S-Bahn* –e.g. *S-Bahn Berlin (SBB)*- that are also operated by *DB Regio Schiene*. Therefore, this section of DB runs both, the commuter rail (*S-Bahn*) and regional services.

In the German case, the difference between commuter and regional rail transportation is clear. The commuter rail services, as defined before, connecting the cities and towns within a metropolitan area. In Germany, there are five clear metropolitan areas: Berlin, Munich, Hamburg, Stuttgart and Frankfurt am Main (*Rhein-Main* metropolitan area). Therefore, there are just these five *S-Bahn* services. All the other routes that connect the different cores inside a region are run by regional services.

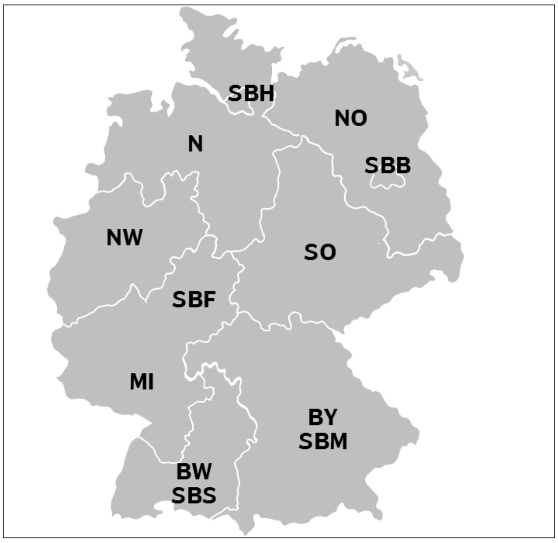


Fig.19. DB Regio Schiene map (Source: dbregio.de).

3.3. Legal aspects

In legal terms, many laws and decrees regulate the Spanish and German railway sectors but both countries have a general and main law that is the base of them. The aim of this section is to have general notions of the legal framework in both countries and to see the level of liberalization or restriction that is present. Both situations are developed in this same section because the EU countries usually have a very similar legislation –many policies are communitarian-.

3.3.1. Spanish legal framework

The railway legislation code in Spain can be divided in three sections: the basic, the specific and the additional legislation. The laws and decrees that compound the basic legislation, cover strictly the railway sector (network, passengers, rail circulation, infrastructure and workers). In the case of specific legislation, bigger scale facts like rail transportation of dangerous goods or regulation of level crossing conform it. Finally, the additional legislation is covered by land transport regulations. All of this legislation code comes from the Ministry of Development. However, the basic legislation is going to be the focus.

This part is basically compounded by two main legal instruments. On one hand and on the top of the hierarchy there is the *"Ley 38/2015 de 29 de septiembre, del sector ferroviario"* –law of the railway sector-. The object of this tool is to regulate railway infrastructures, safety of the railway circulation and to grant the passenger and freight railway services to the rail companies. The main purposes consist in guaranteeing a common railway system around the country by satisfying the society needs in the railway sector with maximum efficiency. Therefore, it generally regulates and establishes the basic guidelines for the railway sector in Spain taking into account infrastructures, service operations and users, including the EU policies of the sector. On the other hand, there is the *"Reglamento del sector ferroviario"* –regulations of the railway sector- approved by *"Real Decreto 2387/2004, de 30 de diciembre"* –real decree 2387/2004-. This instrument defines the Spanish railway network –RFIG- and the elements that integrate it, as well as, the inclusion or exclusion of new railway lines in it. In other words, it is the planning tool of the national railway network.

Going into more detail, Catalonia, Andalucía and Valencian Community are the only regions that also have their own autonomic legislation. In this case, the Catalan law is our focus: *"Llei 4/2006, ferroviària"* –4/2006 railway law-. It regulates railway infrastructures and services belonging to the *Generalitat* competences, always in accord and respecting the Spanish legislation mentioned above. This tool defines the Catalan railway system including the totality of rail routes and services; Renfe and FGC. It is a concrete instrument of the Spanish law but used in a bigger geographical scale that is adapted in the Catalan context.

3.3.2. German legal framework

In Germany, the railway legislation is carried out by *Eisenbahn-Bundesamt (EBA)* –Federal Railway Authority-. This public organization is part of the Ministry of Transport and Digital Infrastructure, and is the maximum authority of the railway sector.

Germany as well has specific decrees that regulate specific parts of the railway sector, but generally, the country has a main legislation: *"Allgemeines Eisenbahngesetz (AEG)"* –General Railway Act-.

The AEG obligates railways to operate safely and to keep the infrastructure, accessories and trains in a safe working condition with the aim of providing the best transportation services possible. It also sets the maintenance guidelines/regulations, supervision, and planning aspects. This law is also responsible for the implementation of EU policies in the railway field. In other words, it ensures safe railway operation, attractive transport service, and effective competition in the provision of rail transport services and in the operation of railway infrastructure.

Other railway types such as maglev trains, trams, mountain railways and other trains with a special design are not covered by AEG. However, these are not comprised in this project.

The General Railway Act contains a large number of subordinate laws that cover the whole railway legal code:

- EIBV –*Eisenbahninfrastruktur-Benutzungsverordnung-.* This long German name refers to the railway infrastructure usage regulations; becoming the non-discriminatory use of the infrastructures.
- EBO –*Eisenbahn-Bau- und Betriebsordnung-.* This legal tool refers to the railway construction and operating regulations.
- BEVVG –*Gesetz über die Eisenbahnverkehrsverwaltung des Bundes-.* Referring to the Federal Railways Traffic Administration Act, which regulates the transfer of the railway administration tasks to the Federal Railway Authority.

These are just some examples of the main subordinate legal ordinances of the AEG. Therefore, Germany has a good organization level, having the main law and all the other laws that operate within and complement it, as mentioned above.

4. Analysis of the study cases

4.1. Analysis: R3 line of Rodalies Catalunya. Barcelona- Vic

The line 3 of the Catalan middle distance services –*Rodalies de Catalunya*- connects the metropolitan area of Barcelona with the Pyrenees. It starts in *l'Hospitalet de Llobregat* and ends in *Latour-de-Carol.* Along this route, there are two sections: from L'Hospitalet to Vic, with a higher frequency of trains and considered a full commuter rail section, and from Vic to Latour-de-Carol, with fewer trains and considered a regional service section. To adjust the route with the needs and target of the project, it is convenient to take only from the first section of the R3 line (L'Hospitalet to Vic) the route from Barcelona to Vic. A route from a metropolitan area to an inside small city as Vic (Fig.20).

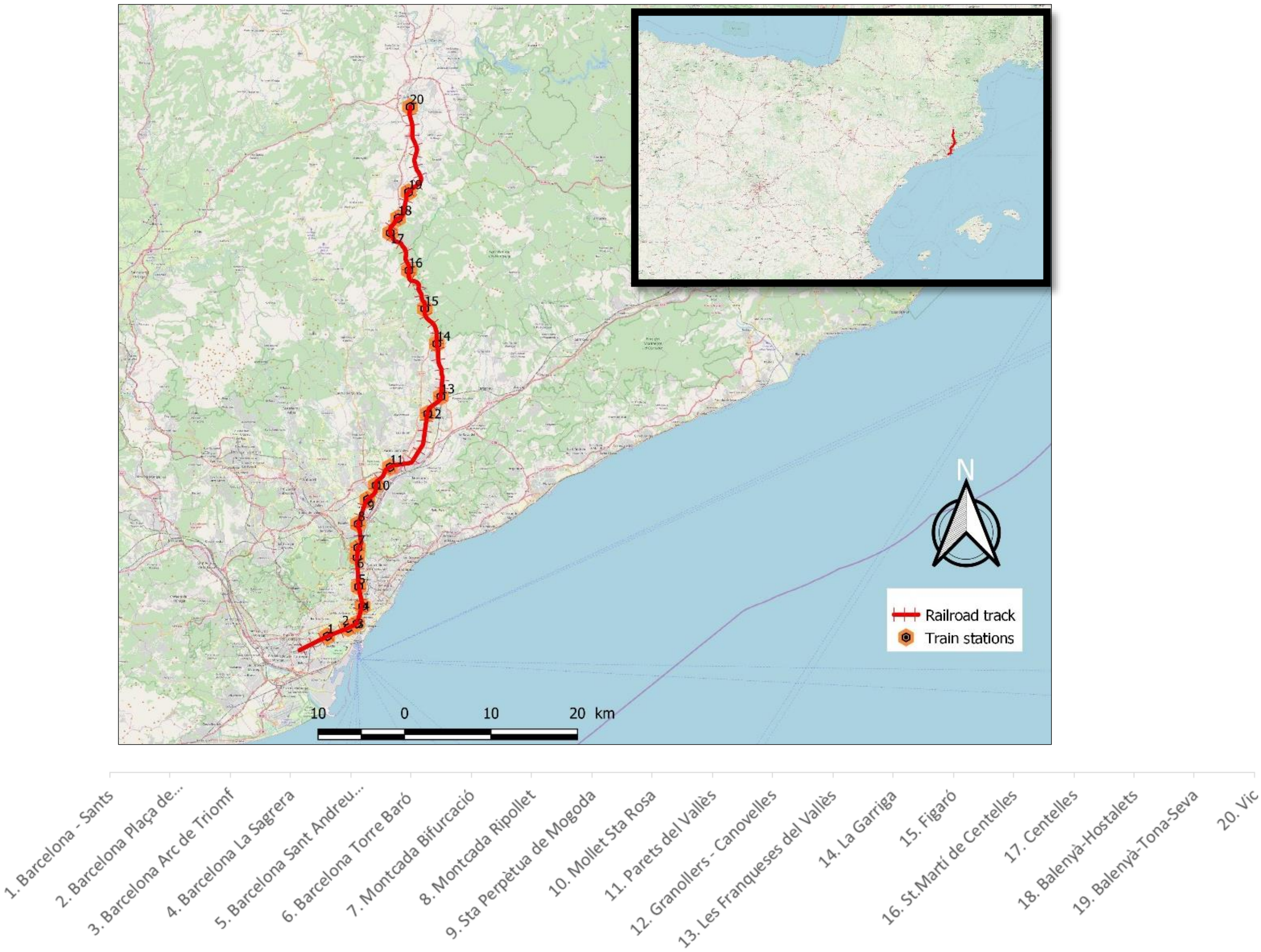


Fig.20. Map of the section R3 Barcelona-Vic, with location and scheme with the stations attached (Source: Own elaboration with QGIS and Excel).

This R3 section has a total distance of 73km. It leaves from the main train station of Barcelona, Barcelona-Sants, and crosses the Catalan capital through a tunnel until Montcada Bifurcació station. Once here the route has only single track. It goes through

Vallès Oriental area –Mollet, Parets, Granollers-, up following Congost River Valley and with a sinuous route until it gets to Osona. There, the flat topography of the Plain of Vic makes the itinerary faster until it gets to the destination: Vic train station. Therefore, from the center of the Barcelona metropolitan area, going through the industrial area that surrounds it, until the sixth and last metropolitan crown still considered part of this area by the ATM (Fig.21).

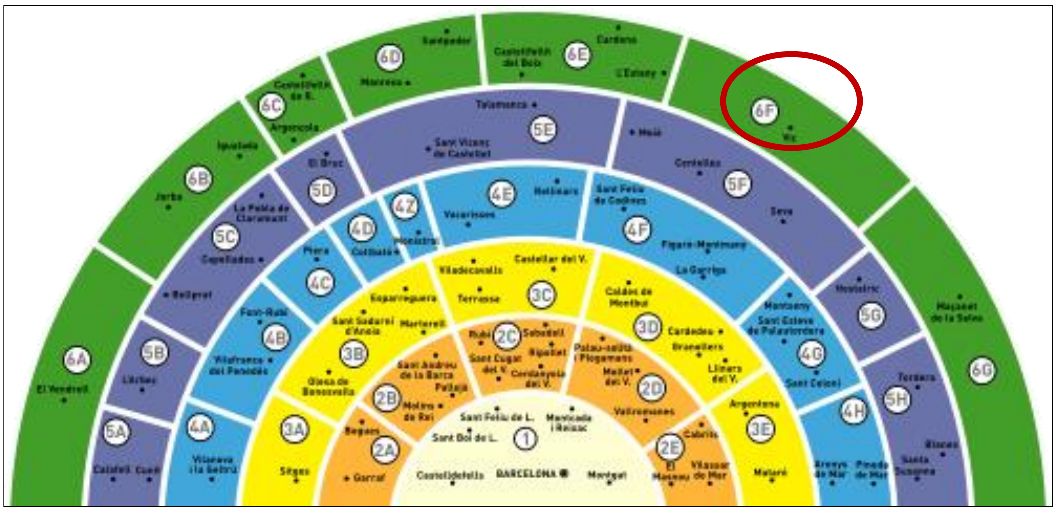


Fig.21. Zoning scheme of the Barcelona metropolitan area used by the public transport services (Source: tmb.cat).

Even though there are projects to implant double-track, currently the route has single-track conditions and it seems that there is no interest from the authorities to apply any of the projects. The duplication of the track from Montcada Bifurcació until Vic has been a claim since the 80's, which has been mentioned in all the public transport plans elaborated by the Catalan government. For example, according to the Catalan plan "Pla Director d'Infraestructures de transport públic col·lectiu de la RMB 2011-2020", the double track construction should have started in 2015. However, the money comes from the Spanish Ministry of Development and this organization keeps rearranging the topic. Along this section, there are 20 stations –see fig.20 map- and every working day 28 trains of the 447 series operate it.

In terms of passengers, this R3 part has an average of 20.956 users per working day and 6.2 million of passengers per year (Estudio de Aforos, 2008). It is a highly used line according to the numbers, but having a single track generates several punctuality and frequency problems. According to the statistics of the organization in defense of the R3 line "Defensem R3", just the 25,4% of trains in 2014 went from Ripoll to Barcelona with a <= 5min delay. The other 74,6% had longer than 6 min delays in working days. The average delay per operation in 2014 was 10 min 18 sec, which means that the trains took around 2 hours to make a little more than 100km.

An important aspect to consider in the duration of this route is the morphology of it, by having –in general- curvature radii of more than 500m. This is one of the reasons of the low velocities, in which the maximum velocity of the itinerary remains in 100km/h and the average duration from Barcelona-Sants to Vic is 1h 22min depending on the stops. According to that, the average velocity of the route remains around the 53,4km/h. In this last value, there are two facts to considerate: the single track and the infrastructure maintenance. In the first place, due to the single-track condition, the trains need to stop at some point of the route –usually in Montcada Bifurcació- to let pass the train that comes from the opposite direction by increasing the time of the journey. Secondly, the infrastructure conditions is another aspect to take into consideration because the trains operate on old platforms and catenaries in which the regular maintenance and management is almost inexistent. That is why this last year there have been several breakdowns and train accidents in the different middle distance lines, and the speed of the operations is as limited. There is an average of 60 incidents per day within commuter rail and regional services, in which the 40% is caused by Adif infrastructure problems, 25% for Renfe material breakdowns, and a 35% for other causes like meteorological conditions, vandalism or collisions (Ministerio de Fomento, 2018). So, the majority of the accidents or breakdowns could be avoided with a decent and rational management and maintenance. In 2015, R3 became the Rodalies line with more incidents by having an average of more than one per day and consequently the most delayed one since there is a single track (Solé, 2015).

Taking into account the train frequencies, there are three differenced sections: from Sants to Granollers-Canovelles, from Granollers to La Garriga and from here to Vic (AMTU, 2016). In the first section there are trains every 30 minutes approximately and in the rush hours every 15-20min. In the second section, the frequency is mainly every 30-40min and every 20min in the peak hours of the day. Finally, from La Garriga to Vic, there are trains mostly every 40-50min and in the rush hours every 20-30min. Therefore, as one moves away from the metropolitan area and gets into the inner cities, the frequency of the service decreases because of the lower demand of users. The next Fig.22 table shows the train schedule and journey time of a regular weekday:

Barcelona Sants Departure (h)	Arrival in Vic (h)	Journey time	Barcelona Sants Departure (h)	Arrival in Vic (h)	Journey time
5:11	6:38	1h 27min	14:30	15:57	1h 27min
6:02	7:21	1h 19min	15:01	16:16	1h 15min
6:22	7:42	1h 20min	15:49	17:13	1h 24min
7:01	8:25	1h 24min	16:10	17:34	1h 24min
7:49	9:23	1h 34min	17:02	18:12	1h 10min
8:22	9:54	1h 32min	17:32	18:59	1h 27min
9:01	10:23	1h 22min	18:27	19:34	1h 7min
9:51	11:14	1h 23min	18:36	20:04	1h 28min
10:22	11:46	1h 24min	18:57	20:16	1h 19min
11:22	12:51	1h 29min	19:21	20:45	1h 24min
12:02	13:22	1h 20min	20:12	21:27	1h 15min
12:33	13:52	1h 19min	21:02	22:23	1h 21min
13:03	14:25	1h 22min	21:32	22:56	1h 24min
14:02	15:18	1h 16min	22:30	23:49	1h 19min

Fig.22. Train timetable for a working day in 2019 (Source: Own elaboration with Renfe data).

As the Fig.22 table shows, the journey time is variable depending on the number of stops that each service does. This is conditioned by the demand of users of each particular station (see in Fig.23. the users flow per station). For example, the small stations like St.Martí de Centelles have much less users than a station like Vic or Granollers-Canovelles, therefore the trains stop there just certain times a day. In the R3 case and as is noticeable in the previous Fig.22, most of the services stop in all the stations, some of them are semi-direct and just one is direct at 18:27h.

Even though the data from Fig.23 is quite old, the current tendencies follow the same pattern.

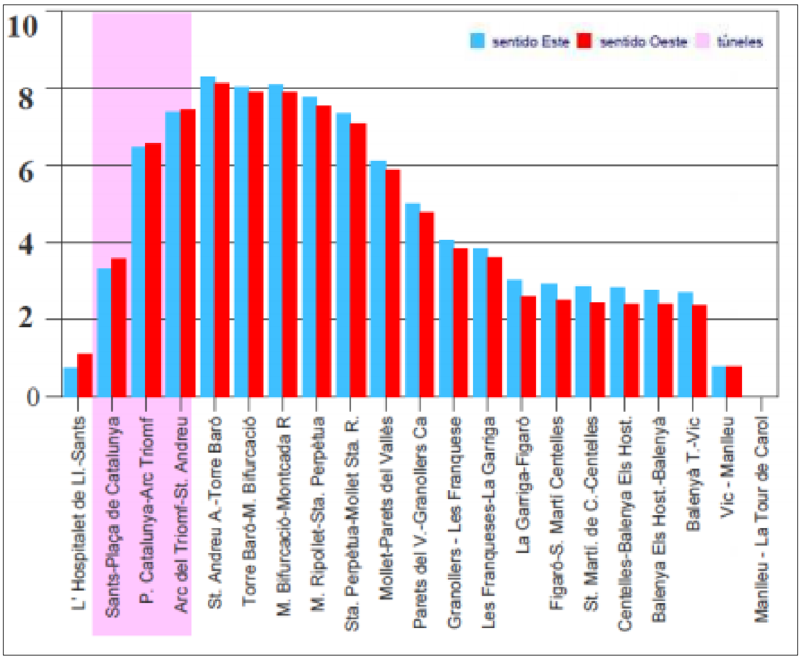


Fig.23. Bar chart of the daily users flow in thousands per station (Source: Plan de Cercanías 2008-2015).

Finally, in terms of tariffs, one way with the R3 until Vic having a single ticket costs 6,30€ and it is variable depending on the metropolitan crowns that the user does. Ex: 1 zone costs 2,20€, 2 zones costs 2,55€, 3 zones 3,50€ and so on. There are also student cards, monthly tickets or other travel cards that make each journey much cheaper.

To summarize all this information, here there is provided a table with the most relevant data:

Route	Barcelona-Vic (R3 section)
Distance (km)	73
Nº stations (total)	20
Avg.Time (regular service)	1h 22min
Elevation gain (approx)	750m
Max.Speed	100km/h
Avg. Speed	53km/h
Train operations	27
Track conditions	mostly single track electrified
Nº users	20.956/working day and 6.2 milion/year
Single ticket price	6,30 €
Management type	less frequency and bigger investments
Locomotive model	serie 477 electric

Fig.24. Table summary of the R3 section (Source: own elaboration)

4.2. Analysis RB22: Frankfurt Hbf – Limburg Lahn

The route RB22 from Frankfurt Hauptbanhof (main train station) to Limburg an der Lahn is a regional route in the Bundesland (federal state) of Hessen. It goes from the Frankfurt metropolitan area to a small city as Limburg an der Lahn is, with 45km^2 of surface and 35.000 inhabitants approximately. In this case, the destination is not considered part of the MA; it is the capital of the Limburg-Weilburg federal district. Therefore, it is operated by the regional services of DB Regio and not by the German commuter rail S-Bahn. Additionally, there are a few ICE trains that go to Limburg an der Lahn, but they stop in Limburg Süd instead of the main station (Lahn) and use a different track itinerary. However, the Fig.25 route is exclusively for the RB22 regional services.

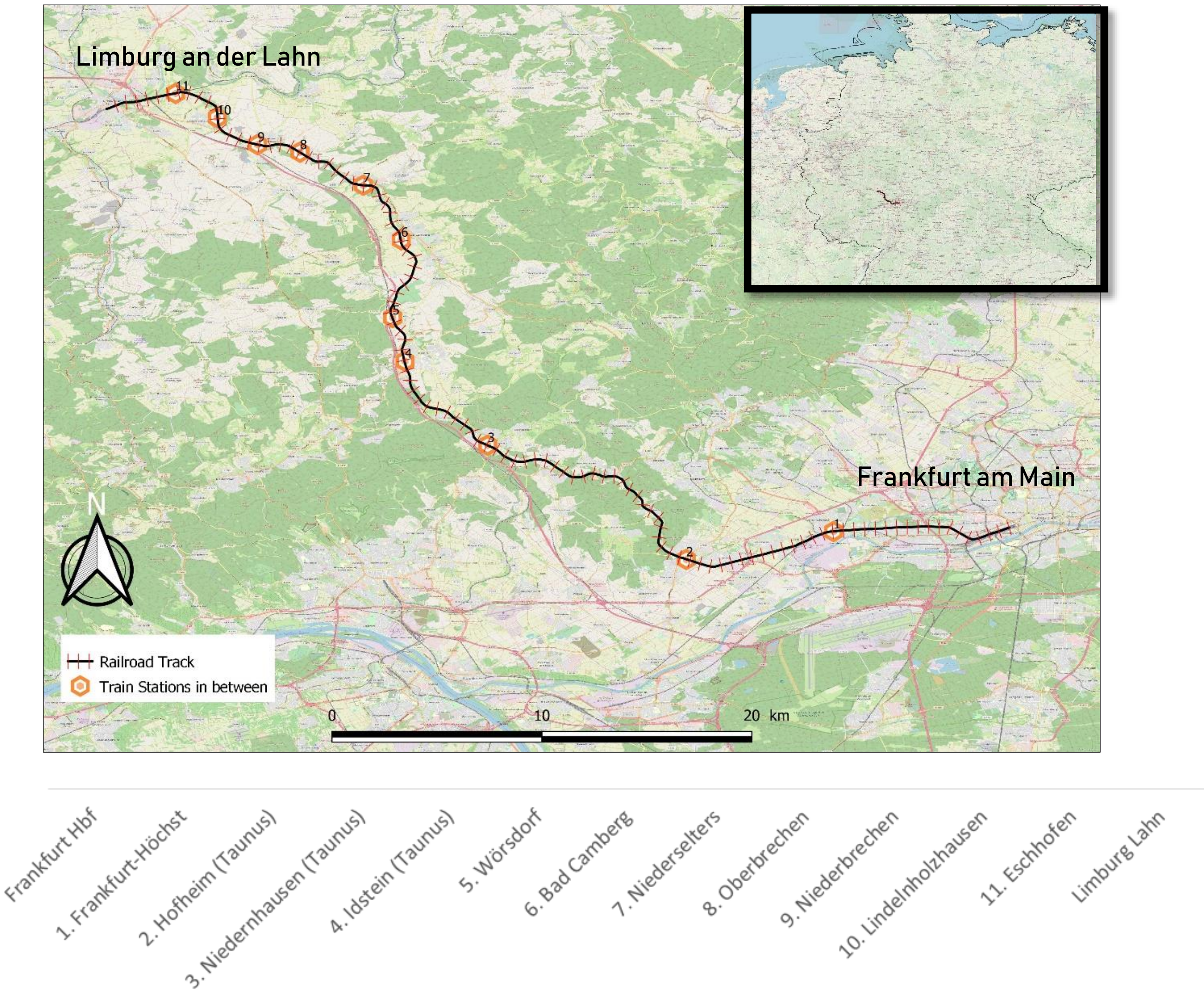


Fig.25. Map of the RB22 route, with location and scheme with the stations attached (Source: Own elaboration with GPS, QGIS and Excel).

This route has a distance of 71 kilometers and eleven stations between Frankfurt Hbf and Limburg Lahn station (Fig.25 map). It starts in the main station of the Hessian biggest city, goes through its metropolitan area, which is mainly composed, by the industrial peripheral areas or cities as Wiesbaden. As this metropolitan area is not very big and the Frankfurt Hbf is located in a place close enough from other federal districts, the second stop is already in the Taunus Mountains, which obviously are not part of the MA. Advancing through this mountain range, the topography becomes more rugged but the trajectory of the tracks keeps straight and with low curvature radii. After that, the rural environment will dominate until the city of Limburg, which is the biggest settlement of the area. An advantage of this itinerary is that the rail track follows a very similar trajectory as the highway 3 (Autobahn 3) and it is a positive fact for the route morphology which keeps mostly straight the whole time. To sum up with the description, this route starts in a major urban core, goes through a mountain range and gets into a rural area that dominates most of the itinerary; the transition from an urban to a rural environment.

This line, as most of the regional lines in Germany, has double track conditions and it is electrified in its totality. The standard train that operates it is the model 143 637 with 3 to 5 wagons. An electric train with a maximum speed of 120km/h. This value is the velocity limit of most of the regional lines in the country and has been for years the highest safe speed. According to the next Fig.26 table, the average duration of the route is 1h 11min. This depends on two facts: stops and type of service. On one hand, the stops that the train does or even the layovers predetermine the time duration. For example, the fact that there are routes which take 1h19min is because usually there is a layover of 5min in Niedernhausen (Taunus). On the other hand, the service type is a key fact for the duration. For example, the journeys that last 1h03min are regional express services. Therefore, the regular service takes 1h 11min approx. which means that the average velocity is 60km/h (including the stops) and the regional express service takes 1h03min that supposes an average speed of 67,6km/h. These velocity values seem quite low taking into account that there is a double track and consequently less traffic since it is divided in two. However, the service offered is effective.

In terms of demand, it is a highly demanded line as mentioned above. Unfortunately, DB maintains most of its data private. This is the reason which justifies the lack of figures or specific numbers given in this section relating to users. Nevertheless, German regional services have much more demand than the Spanish ones only with the simple fact that the amount of annual middle distance users is four times bigger -450 million in Spain (2017, Adif) and 1930 million in Germany (2017, DB)- and the total population difference is not as different -46,53 million in Spain (2017, Eurostat) and 82,79 million in Germany (2017, Statistisches Bundesamt)-.

Punctuality is another relevant variable to analyze. In this case, the specific data of this route is private as well. Although, the RB22 is usually on time and if any time a delay takes place, it is mostly lower than 5 minutes unless it is an actual train accident (e.g. suicide, train collision, etc.). Proof of this fact is that in 2018, there were 57.018 delay minutes in this specific regional line. Therefore, there was a delay average of 4min 18sec per operation (Trottmann, 2019).

The train frequency is also an important fact to observe. There are 36 train operations per day in this regional route. These operations are divided in every 10-20min in the rush hours and every 30-50 min in the other times of the day:

Frankfurt Hbf Departure (h)	Arrival in Limburg Lahn (h)	Journey time	Frankfurt Hbf Departure (h)	Arrival in Limburg Lahn (h)	Journey time
5:22	6:41	1h 19min	15:42	16:56	1h 14min
6:01	7:11	1h 10min	16:01	17:04	1h 03min
6:13	7:26	1h 13min	16:13	17:26	1h 13min
6:43	8:01	1h 18min	16:22	17:41	1h 19min
7:31	8:41	1h 10min	16:43	17:56	1h 13min
7:52	9:11	1h 19min	17:01	18:04	1h 03min
8:31	9:41	1h 10min	17:12	18:26	1h 14min
9:31	10:41	1h 10min	17:30	18:41	1h 11min
10:31	11:41	1h 10min	18:01	19:04	1h 03min
11:31	12:41	1h 10min	18:31	19:41	1h 10min
12:31	13:41	1h 10min	19:01	20:04	1h 03min
13:01	14:04	1h 03min	19:31	20:41	1h 10min
13:31	14:41	1h 10min	19:52	21:11	1h 19min
14:01	15:04	1h 03min	20:31	21:41	1h 10min
14:31	15:41	1h 10min	21:31	22:41	1h 10min
15:01	16:04	1h 03min	22:31	23:41	1h 10min
15:13	16:27	1h 14min	23:22	0:41	1h 19min
15:22	16:41	1h 19min	0:28	1:41	1h 13min

Fig.26. Train schedule in a working day of 2019 (Source: Own elaboration with DB data)

In terms of infrastructure management, DB Netz distinguishes five types of infrastructure –catenary, track, switches and crossings, lights and crossing levels- and three periods of maintenance –three months, six months and twelve months- (Trottmann, 2019). These periods vary depending on the infrastructure type and are imposed by the General Railway Act (AEG). Therefore, a frequent management that brings the German trains to barely have infrastructure problems and be leaders of Europe in terms of infrastructure and maintenance.

The problem that affects this route and some others is the traffic management. This fact caused the few train accidents in Germany occurred these past years, for example the collision of trains for letting pass a train in a single track section when another locomotive was coming from the other direction. Apart from that, the knock-on delays have been a more frequent problem and the base of most of the daily issues (these incidences that happen in a line –e.g. when it is delayed- and affect to the other lines around). Although, this is also a problem based on the traffic management.

According to the tariffs, a one way single ticket costs 12,35€. This ticket seems quite expensive but there is one aspect to take into account: Germany has a high standard of living in comparison to other regions –fact that makes the price equivalent-. In addition, the population segments that cannot afford this price such as students, as this is public transportation and it is a public service, there are travelling cards that make it much cheaper.

To summarize all this information and have a better understanding of it, the upcoming Fig.27 table shows the most relevant data from this route explained so far:

Route	Frankfurt (Hbf)-Limburg(Lahn)
Distance (km)	71
Nº stations (total)	13
Avg.Time (regular service)	1h 11min
Elevation gain (approx)	400m
Max.Speed	120km/h
Avg. Speed	60km/h
Train operations	36
Track conditions	double track electrified
Nº users	No open data available
Single ticket price	12,35 €
Management type	Continuous
Locomotive model	BR 143/637 electric

Fig.27. Table summary of the RB22 line (Source: Own elaboration)

5. Improvement Project of the Rodalies R3 line

5.1. Diagnosis

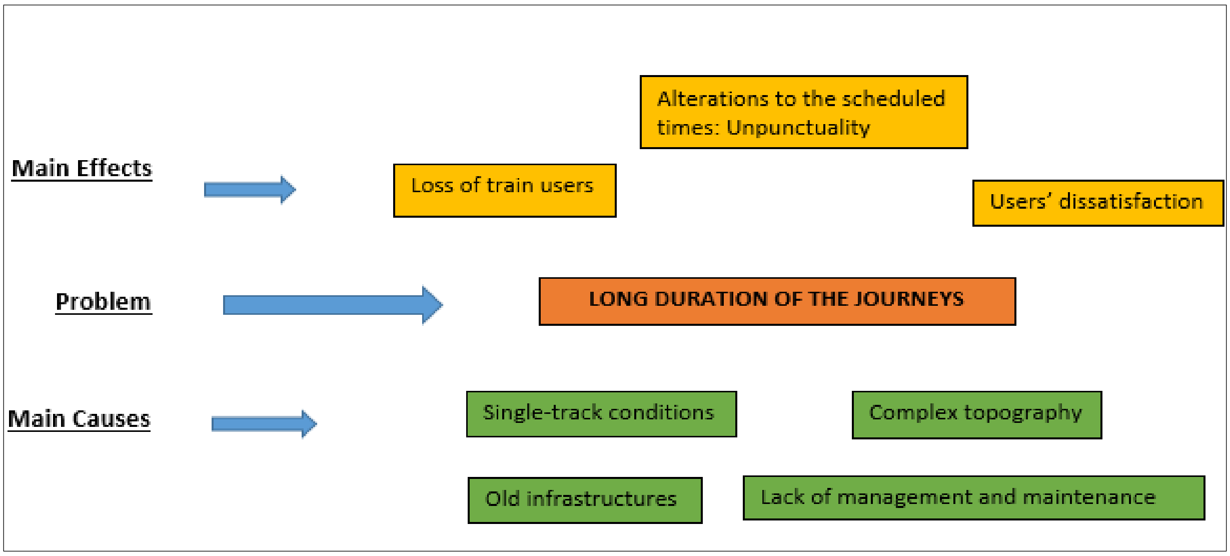
Once the analysis phase is done and the two railway systems and routes have been exposed and analyzed, it is time to diagnose the positive and the negative aspects of the Vic-Barcelona section from R3 line (the improvement object). This diagnosis is going to be carried out –as mentioned previously in the methodology-, with the following SWOT matrix and a problem tree for the main two issues identified.

	Internal	External
	Weaknesses	**Threats**
–	• Irregular management and maintenance of the infrastructures. • Single track conditions in most of the itinerary. • Poor traffic management, which is noticeable with the daily incidents and knock-on delays. • Generalized unpunctuality. • Some train stations, such as Balenyà-Tona-Seva or St.Martí de Centelles, have deficient loudspeaker announcement services. • Some stations do not have information offices or even ticket machines to buy them. • Noncompetitive duration of the journeys, being this almost the same with 20th Century.	• Irregular topography that affects negatively the infrastructure establishment. • Lack of interest from the government to invest; it is seen as loss making sector. • Priority of the AVE in the public investments, even though the regional and commuter rail services are much more demanded. • Commuter rail network that is used to cover a whole Autonomous Community, with only a few regional lines. • Radial structure of the Catalan railway network –with Barcelona as its core-due to the fact that is mainly composed by Rodalies services. It should integrate and connect the whole territory itself and not mostly with Barcelona.

	Strengths	Opportunities
+	• Good train frequencies according to the demand of each station. • Cheap tariffs according to the public service that is –even with the single ticket-. • Due to the life style and the needs of the inhabitants around Vic, an itinerary from Vic to Barcelona will always be highly demanded.	• The number of users keeps high –around 25 million per year (Adif, 2016) - and slowly increasing despite the quality of the service. • Sustainable mobility model and environmentally friendly. • Safer mean of transport. • Redistributive function of the mobility flows by reducing private transport, which consequently would reduce road congestion. • Positive climate conditions for an optimal running of the services and infrastructures. • Safe mean of transportation and even more because of the bigger Iberian gauge, which guarantees more stability.

Fig.28. SWOT matrix of the Vic – Barcelona R3 section (Source: own elaboration).

According to the Fig.28. SWOT analysis, long duration of the journeys and lack of public investment are two of the important issues. They are the problems which the population of the territory complains the most (Fosas, 2019). Due to this fact, the following Fig.29 will show more graphically –through a problem tree analysis- the main causes and consequences of those two issues as another example of diagnosis methodology.



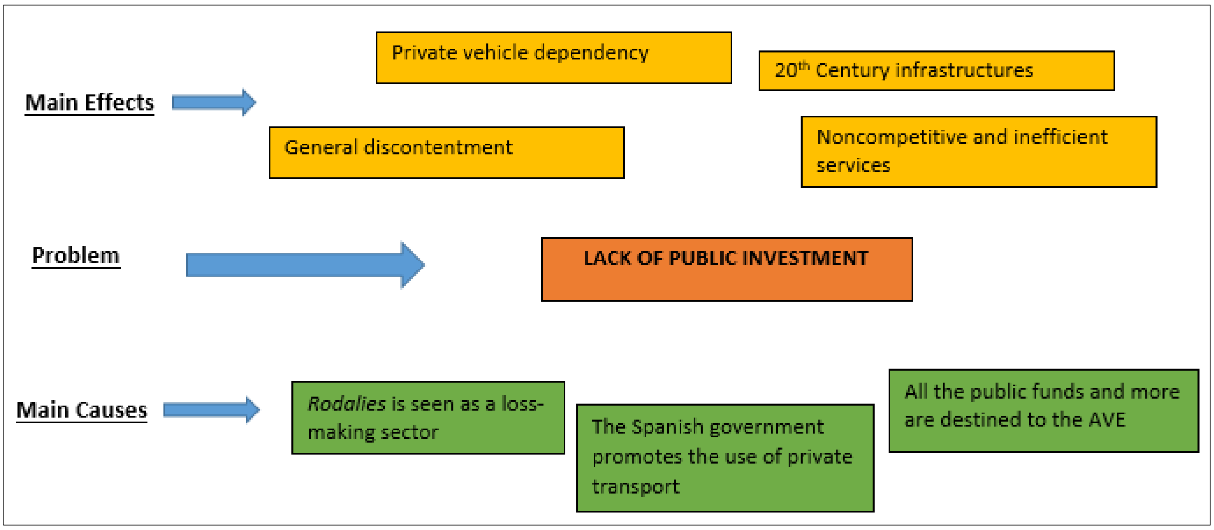


Fig.29. Problem tree schemes of the two most relevant issues from the users' view (Source: own elaboration).

5.2. Prognosis

After diagnosing the positive and the negative aspects of the current R3 selected section, the proposal of solutions will be presented as a set of seven measures focused on the optimization of the line. These solutions will be exhibited through the actors which execute them, the investment level (high, medium, and low), and a further explanation, which in some cases will be complemented with cartography or other competent figures.

Measure 1: Double track implementation

Explanation	Actors	Investment Level
Create and implement double track conditions between the stations of Montcada-Bifurcació and Vic. There are projects already done relating to this issue. Therefore, there would only be a checking and an execution phase. For example, the Railway Infrastructure Plan for Barcelona *Cercanías 2008-2015* or Catalan plan *“Pla Director d’Infraestructures de transport públic col·lectiu de la RMB 2011-2020”* propose it. The output would be a double track route with fewer delays and faster times since the train would not need to let the one coming from the other direction pass. In addition, the number of knock-on delays would be reduced as well. A major conflictive point in the construction of the double track would be in Congost River Valley, where the solution would be a construction of a tunnel to go through it –Fig.31- and consequently reducing the most sinuous part of the route by making the train able to operate in faster velocities.	- Spanish Government (Ministerio de Fomento). - Generalitat de Catalunya. - Adif. - Other construction and railway material companies.	High

Fig.30. Measure 1: Double track implementation (Source: own elaboration).

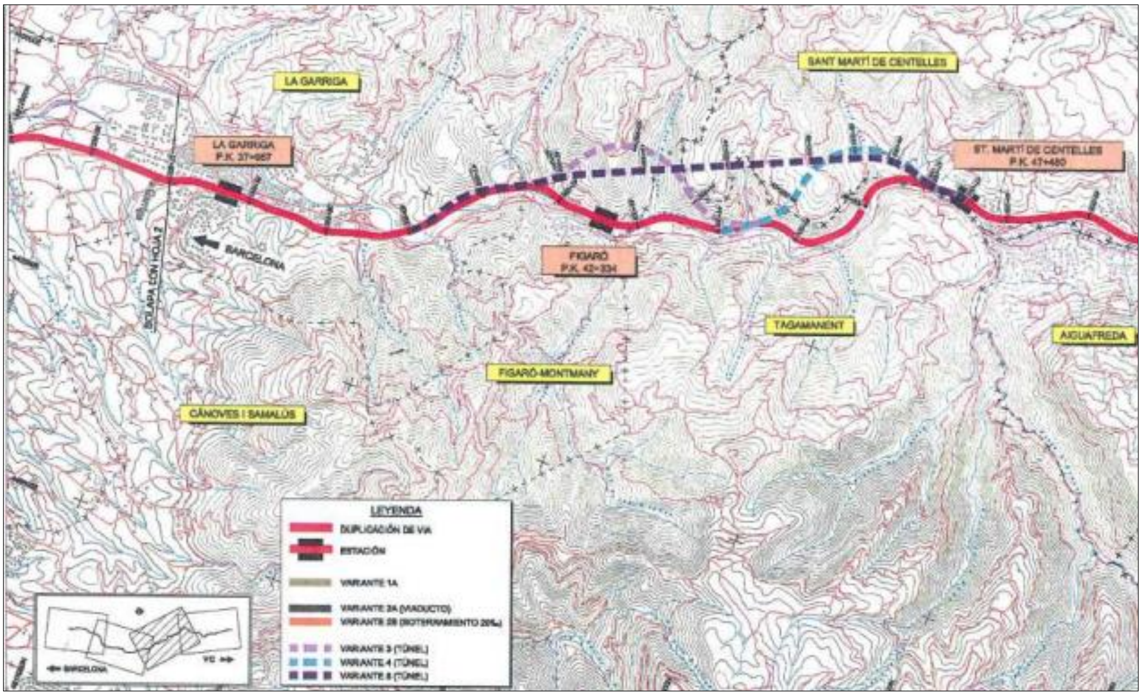


Fig.31. Topographic map of the tunnel construction alternatives. This project supports the construction of the 5th variant (the most straight one) (Source: Estudi informatiu de duplicació R3, 2008).

Measure 2: Continuous infrastructure management

Explanation	Actors	Investment Level
Taking as a sample the German management methods, there is the need to implement trimestral and biannual infrastructure management periods – differentiating the infrastructure types-, to ensure the perfect status of them by making the route safer and with less train movement or noises. Additionally, the locomotives would be able to operate the route in	- Spanish Government (Ministerio de Fomento) - Generalitat de Catalunya - Adif - Renfe Operadora	Medium

faster velocities; new technology automatized that would allow better traffic management and newer security systems.		

Fig.32. Measure 2: Continuous infrastructure management (Source: own elaboration).

Measure 3: Reduction of the commuter rail itineraries by promoting and creating pure regional services and routes

Explanation	Actors	Investment Level
The Catalan territory should be net-connected instead of having a radial structure in railway networking terms. Therefore, the commuter rail services would be exclusively used for interurban-metropolitan transportation with a maximum operation radius of 50 km from its core (Barcelona). From this distance, the regional services would start operating and articulating the rest of the Catalan region (radius from 50 to 150km). According to that, ATM should redefine its competences as well as Rodalies, and this being the last entity changed to Renfe Regional when convenient due to the radius criteria exposed below (and graphically represented in the next Fig.34 map). In this way, the main middle distance routes, like R3, would reduce their duration by having less stops and consequently offering competitive times. The output of this third measure would be a new regional service from Vic to	- ATM (Metropolitan Transport Authority) - Renfe Operadora (Rodalies and Regional) - Adif - Generalitat de Catalunya - Spanish Government (Ministerio de Fomento)	Low - Medium

Barcelona, which would avoid half of the current stops.		

Fig.33. Measure 3: Reduction of the commuter rail itineraries by promoting and creating pure regional services and routes (Source: own elaboration).

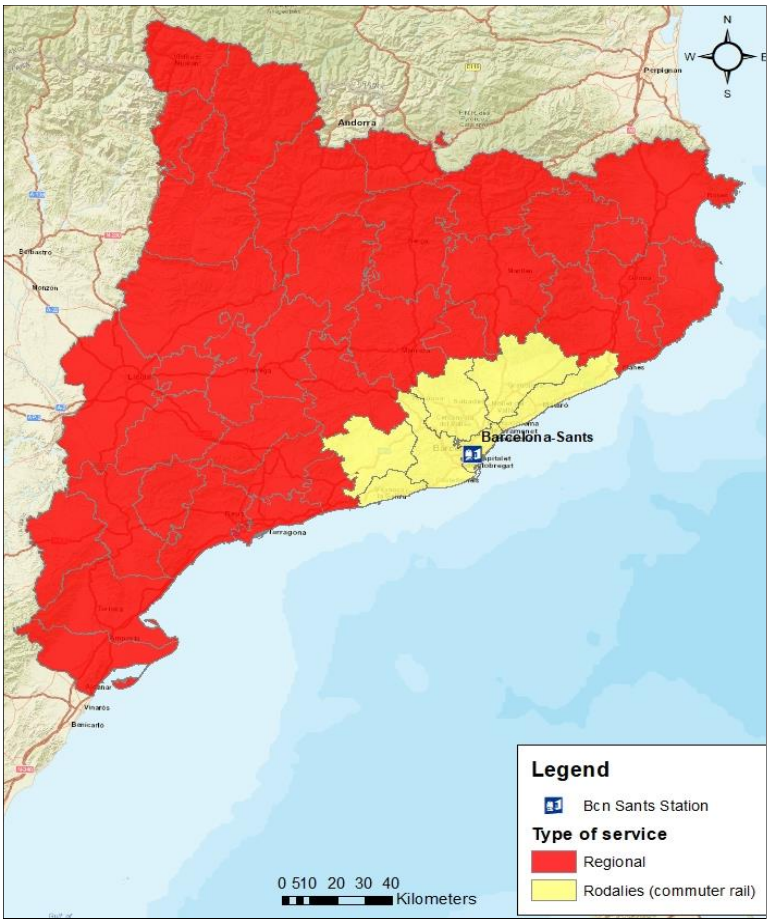


Fig.34. Map of the new delimitation of services proposed in the third measure (Source: Own elaboration with ArcGIS).

Measure 4: Efficient traffic management system adapted to the IT era

Explanation	Actors	Investment Level
There has to be a full implantation of a regional ERTMS (European Rail Traffic Management System) in the R3 route and in the entire Catalan railway network as soon as possible. This system is launched by the EU and is already implemented in many high velocity European networks but not in regional services yet. It aims to	- Spanish Government (Ministerio de Fomento) - Generalitat de Catalunya - Adif - Renfe Operadora	Medium - High

improve safety, making the rail routes more efficient and improving the cross-border interoperability in the European context. In the R3 case, this implantation would trigger the digitalization and automatization of it by having constant real time data which would be the input to control and manage the operations efficiently. In this way, the regional services would be similarly managed like the most efficient trains in the world (AVE, ICE, Thalys, Maglev…) and introduced to the Big Data era. Nevertheless, the cost would be lower than these high velocity services due to the shorter distances and having obviously less sensors and signals than the high velocity lines –fact that would reduce costs-.	- IT and Geoinformation managers. - European Union Agency for Railways (ERA)	

Fig.35. Measure 4: Efficient traffic management System adapted to the IT era (Source: own elaboration).

Measure 5: Different locomotive models

Explanation	Actors	Investment Level
Due to the high demand of the route and the non-adequate train facilities for a regional route, there is the need to put locomotives with more passenger capacity and more comfort. The 447 series train is adequate for short commuter rail itineraries. However, according to the 3rd measure above, this section should belong to regional services. In this way, the new locomotive model should be similar to the R-449 of Renfe	- Spanish Government (Ministerio de Fomento) - Generalitat de Catalunya - Renfe Operadora	High

(Figs.37&38) with more capacity, better comfort and the ability to circulate in faster velocities.		

Fig.36. Measure 5: Different locomotive models (Source: own elaboration).


Fig.37&38. Middle-distance R-449 locomotive form outside and inside (Source: renfe.com).

Measure 6: Compulsory maintenance of the train stations facilities

Explanation	Actors	Investment Level
The aim of this measure is to keep the train stations in good conditions by guaranteeing basic services and facilities. The train stations of the section should have loudspeaker services working well, crossing levels perfectly coordinated with the traffic management services and in optimal conditions, ticket machines, at least one information office or information staff around each station, toilettes, emergency boxes, bar services or vending machines and benches. All these facilities should obviously be	- Spanish Government (Ministerio de Fomento) - Generalitat de Catalunya - Adif - Renfe Operadora - Local technicians	Low - Medium

well maintained by the station workers.		

Fig.39. Measure 6: Compulsory maintenance of the traint stations facilities (Source: own elaboration).

Measure 7: Security improvement

Explanation	Actors	Investment Level
The R3 is one of the lines in the entire region with the most people who do not pay and in some cases who cause social problems (e.g. stealing). Due to that, there has to be security staff in all the stations and more than one worker as well as inside the train. Additionally, there has to be security cameras and alarm buttons to call security immediately in each locomotive. The train atmosphere has to be completely occupied by civism.	- Generalitat de Catalunya - Renfe Operadora - External security services if necessary	Low

Fig.40. Measure 7: Security improvement (Source: own elaboration).

5.3. Project application and monitoring

To ensure the effectiveness of this project, the phases of application and monitoring will be decisive. Once the project has been created, it is important to remember the fact that there have been many projects or plans which have not been applied or even monitored, and consequently, none of the targets have been achieved. In this case, there is the need to do a guidance section for these following phases.

First of all, this is a big project with an elevated cost which will cover all the current inefficiencies or lacks of the studied section. In other words, it is the solution to become competitive in the regional railway sector –based in a route- and requires a considerable money investment. Having seen the seven measures in the prognosis section, there is no hierarchy or priority order of them to be applied; the mix of them leads to the final solution. It is true that the duplication of the tracks is a very important measure to apply and has been a claim for many years, although applying only this solution means that the problem would just be partially solved. According to that, the project has to be applied in its totality in order to reach the efficiency.

Once implanted, there has to be a continuous management and monitoring process to guarantee its optimal performance. This phase will start three months after the implantation and will take part once every three months for the first two years. The monitoring work consists of assessing the results of the past three months using all the acquired data and users' opinions. If the result were to be negative, there would be the need to detect and solve the issue by incorporating new measures or modifying the current ones. After the first two years, this project monitoring would be done once every six months and the procedure would be the same until the fourth year. Then, if everything has gone well as expected, the success of the plan would be a reality.

6. Conclusions

Having reached the end of the investigation, some observations such as the affirmation or negation of the initial hypothesis, the accomplishment of objectives and other conclusions will be revealed as a final assessment method.

First, the hypothesis has been clearly supported and affirmed. The Rodalies services and Adif infrastructures have been questioned for years by the Catalan population, and in this research all these inefficiencies are put forward, analyzed and subsequently solved by the Improvement Project. Lines like R3 of Rodalies or RB22 of DB Regio have been perfect study cases to enter in depth in these two middle distance train systems. The research objectives have been also successfully achieved throughout the evolution of it according to the project structure and timetable defined in the introductory section. Nevertheless, there have been some problems apart from all of these successfully achieved mentioned aspects.

The first and main problem encountered has been the lack of public data or in other words, the strict privacy of the different railway companies which, in a sense, limited the development of the project. Due to the liberalization of the railway systems explained in prior sections, DB as well as Renfe and Adif are private companies. According to that, they keep most of their data private to use it for their own corporation purposes. Additionally, as the system is liberalized, there is competition and pressure from press and media, and any specific dataset or even figure could generate several problems to any of the companies. Therefore, the investigation had to be provided by public data from the open data portals and public organizations.

Other problems found during the research elaboration have been mainly related to the information absence as well. For example, as the information about regional routes and lines is very poor, the fieldwork results compose most of the study cases and improvement project sections. However, this is also positive since there has been the need to create the missing information (e.g. by using the GPS to create cartographic bases).

Apart from these issues, which were already quite expected in the beginning of the research, the key to avoid most of the possible difficulties, to predict problems and to work orderly has been given by having clear structure and targets defined according to a planning project morphology from the starting point of this investigation.

In thematic terms, the project has accomplished the objectives and confirmed the initial hypothesis as mentioned before, but evidently, it is not the magical formula to have an efficient railway system. The German regional railway system is not perfect, although as it is studied in the investigation, it follows a rational working mode and covers most of the transportation needs of the population. Therefore, this is the reason why this project makes sense, because there is no better proof than the empirical one and if it occurs in Central and Northern Europe, it can be possible in the Southern areas as well.

Nevertheless, the money investment and decision making comes from the governmental authorities. According to this, there can be many projects and proposals, but if the government is not compromised in serving this basic public service then there is no valid solution. The railway can be a perfect measure against climate change, it can stop the private vehicle dependency and give chances to everybody to move throughout the regions, and it is the easiest and the most cost-effective global transportation solution. However, without the compromise of the state and the citizens' support it will continue to be a residual mean of transport as it is now in Spain.

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